

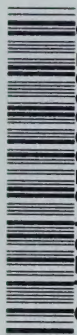
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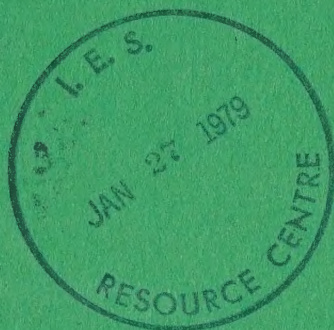
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Water Pollution Control Directorate
June 1978

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LAND APPLICATION OF FOOD PROCESSING WASTEWATER

Design and Operations Manual

by

Stanley Associates Engineering Ltd.

for the

Water Pollution Control Directorate
Environmental Protection Service
ENVIRONMENT CANADA

Report No. EPS 3-WP-78-5
June 1978

REVIEW NOTICE

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ABSTRACT

Application of food processing wastewater to the land as a method of treatment and disposal is a relatively recent development. The current emphasis on reducing pollutional discharges to surface waters has resulted in a wider acceptance of land application as a suitable treatment alternative.

This manual describes the land application systems which have been used in the treatment of food processing wastewaters, and presents a methodology for approaching the design of such a system. The effects of design parameters such as climatic conditions, soil type, hydrogeology, and wastewater characteristics are evaluated, and possible constraints are identified. The manual is intended to provide information useful to the food processing industry in determining the suitability of various land application systems for specific processing wastewaters under varying conditions.

An economic analysis for a typical system is presented, and evaluated using both the annual cost approach and present worth technique.

Fifteen food processing plants using land application for treatment and disposal of wastewaters were surveyed and are described. These included plants processing fruits and vegetables, milk products, and meat products.

RÉSUMÉ

L'épandage des eaux usées provenant de la transformation des aliments sert depuis peu comme méthode de traitement et d'évacuation. L'importance croissante accordée à réduire les rejets polluants dans les eaux de surface a entraîné une acceptation plus grande de l'épandage comme solution de rechange au problème du traitement des eaux usées.

Le présent ouvrage décrit les méthodes d'épandage et présente des façons de les concevoir. On y évalue les effets de certains paramètres comme le climat, les types de sol, l'hydrogéologie et les caractéristiques des eaux usées, en plus d'identifier les contraintes possibles. L'ouvrage devrait permettre à l'industrie alimentaire d'évaluer diverses méthodes pour épandre certains types d'eaux usées, dans des conditions variables.

Nous présentons une analyse économique d'un système typique et nous évaluons ce dernier du double point de vue du coût annuel et de la valeur actuelle.

Quinze entreprises qui pratiquent l'épandage ont été contrôlées et sont décrites. Elles comprennent des entreprises transformant les fruits et légumes, les produits laitiers et les viandes.

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1 INTRODUCTION

1.1 Purpose of the Manual

Application of food processing wastewater to the land for treatment and disposal is a relatively recent development. Because of recent emphasis on the reduction of the pollutorial load discharged to surface waters, there has been a dramatic increase in the number of food processing plants using land application treatment systems within the last 10 or 15 years.

Land application is a suitable alternative for the treatment of food processing wastes for a number of reasons. Firstly, many processing plants are located in rural areas with close access to suitable land. Secondly, food processing wastewaters are generally nontoxic and easily biodegradable. Thirdly, most land treatment techniques avoid the problem of system startup associated with conventional treatment facilities used by seasonal industries.

The purpose of this manual is to describe those land application systems which have been used in the treatment of food processing wastewaters. The capabilities and constraints of each are discussed, pertinent design variables are defined and a procedure for design of each type of system is outlined. The specific information provided is applicable to the design of land application facilities for the treatment of the following types of wastewaters:

- 1) meat and poultry products,
- 2) fish products,
- 3) fruit and vegetable processing,
- 4) dairy products,
- 5) beverage industries.

1.2 The Decision-making Process

Figure 1 illustrates the pertinent steps in the design of a land application facility. Prior to the selection and design of a land treatment system, treatment objectives must be clearly defined. A list of realistic objectives for land treatment systems is given below:

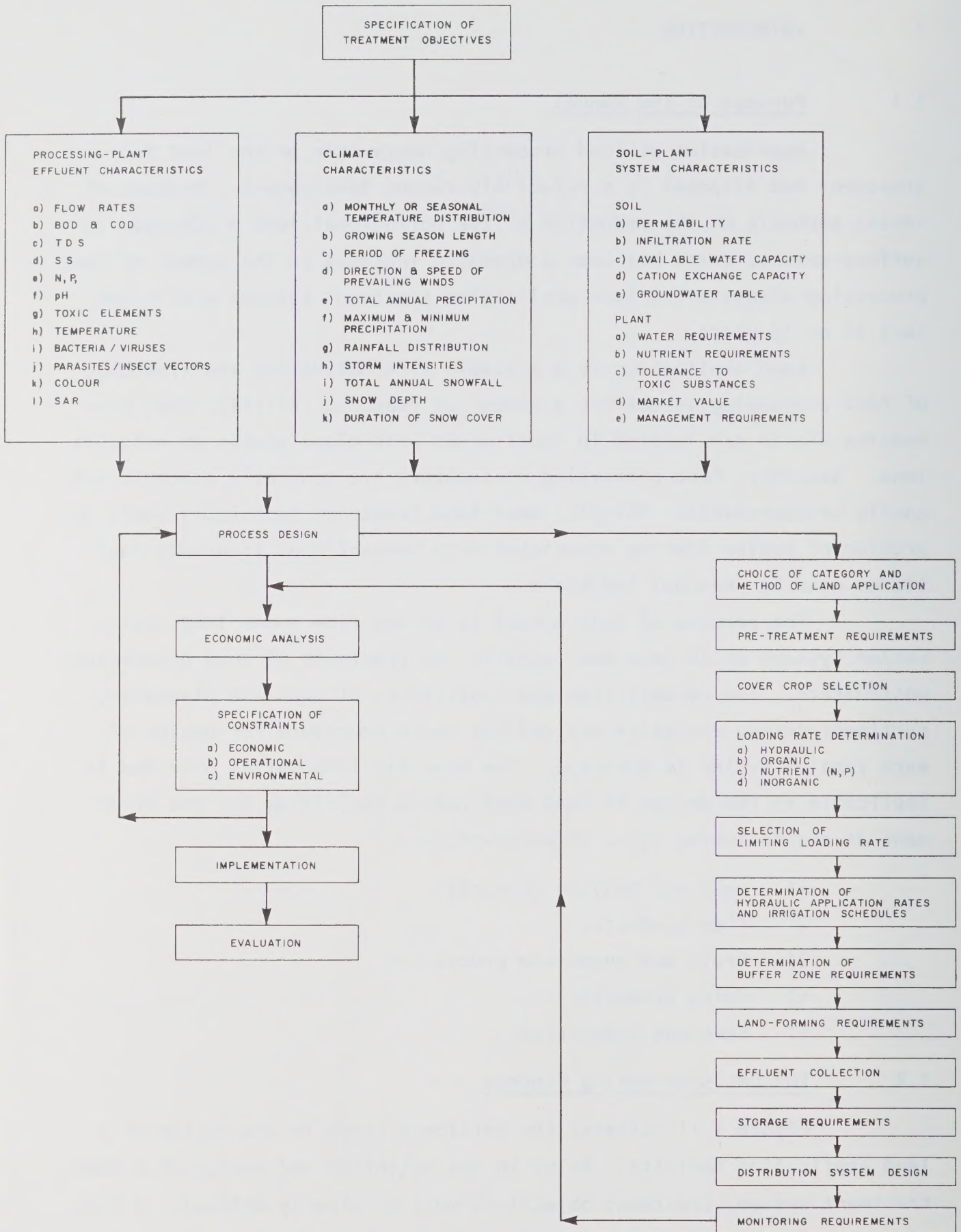


FIGURE 1. FLOW DIAGRAM OF THE DECISION-MAKING PROCESS.

- 1) biochemical oxygen demand (BOD_5) and suspended solids removal,
- 2) nitrogen removal,
- 3) phosphorus removal,
- 4) crop irrigation,
- 5) groundwater recharge,
- 6) renovated water recovery.

The final selection and design of a land treatment alternative will be partially defined by the particular selection of objectives.

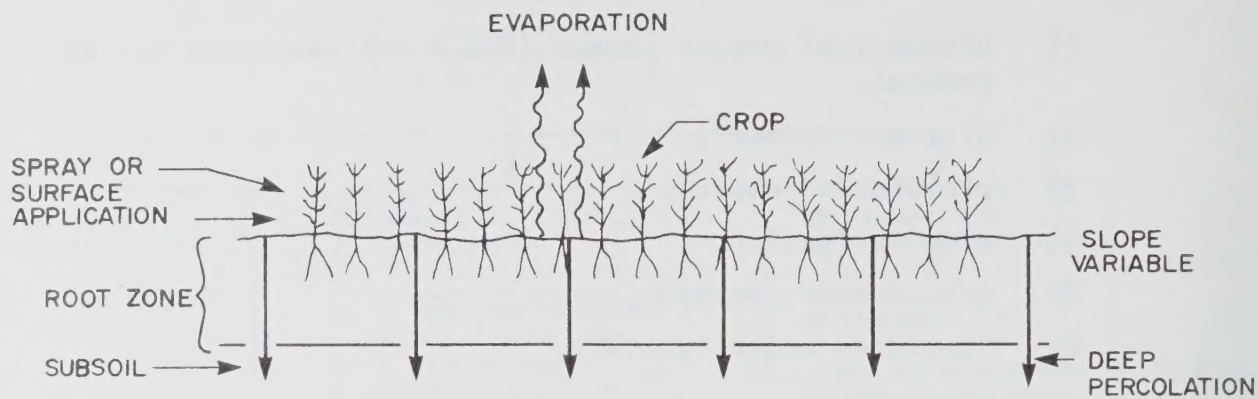
The important variables for design are those associated with the wastewater, the climate, soil characteristics and crop characteristics. Once these variables have been defined, a feasible land treatment alternative may be selected and designed.

The three most common land treatment methods are irrigation, overland flow and infiltration percolation. These are illustrated in Figure 2. Irrigation is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. Overland flow is the spraying of wastewater on vegetated slopes with the removal of pollutants by physical, chemical and biological means; the wastewater flows down the sloped surface and collects as runoff at the bottom. Infiltration percolation is the rapid discharge to land by flooding or spraying with impoundment and no surface runoff. The use of each method in the various land application techniques is summarized in Table 1.

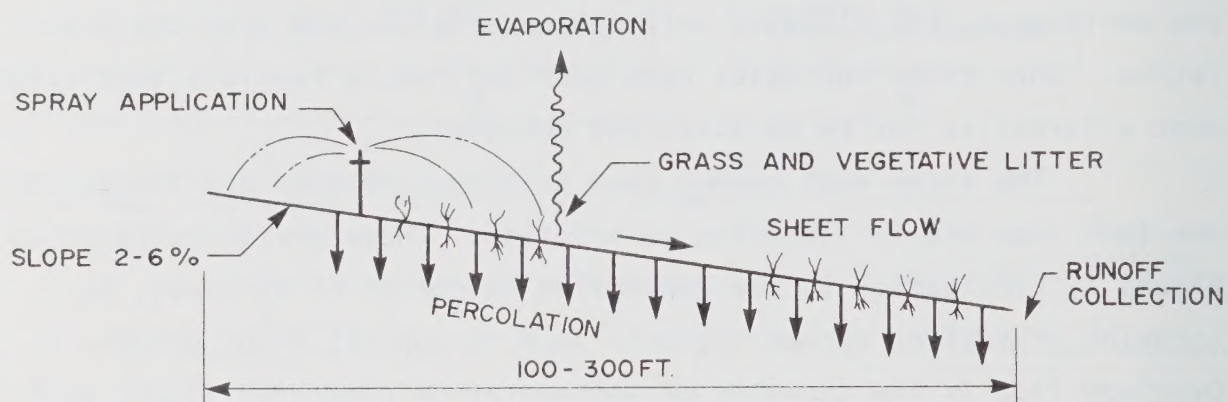
Subsurface methods, including septic tanks and tile fields and deep well injection, may also be feasible treatment and/or disposal methods.

Process design details, summarized on the right side of Figure 1, are discussed in Section 6 of this manual.

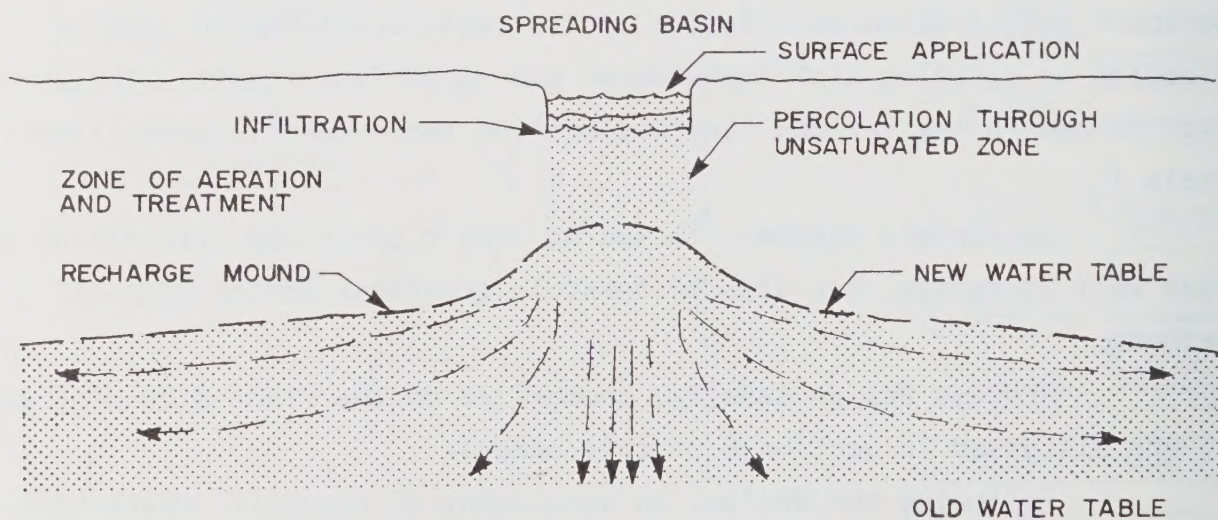
Following the design, an assessment of economic, operational and environmental constraints should be made. The outcome of this assessment may require further analysis of other feasible alternatives in order to select a least cost and/or a design alternative having the minimum constraints.



IRRIGATION



OVERLAND FLOW



INFILTRATION PERCOLATION

FIGURE 2. SURFACE LAND APPLICATION APPROACHES

TABLE 1 COMPARISON OF IRRIGATION, OVERLAND FLOW, AND INFILTRATION PERCOLATION OF WASTEWATER

Land Application Objective	Application Method		
	Irrigation	Overland Flow	Infiltration Percolation
Used for recovery of renovated water ^a	0 - 70% recovery	50 - 80% recovery	up to 90% recovery
Used for treatment beyond secondary:			
1) For BOD ₅ and suspended solids removal	98+%	92+%	85 - 99%
2) For nitrogen removal	85+ ^b	70 - 90%	0 - 50%
3) For phosphorus removal	80 - 99%	40 - 80%	60 - 95%
Used to grow crops for sale	Excellent	Fair	Poor
Used as direct recycle to the land	Complete	Partial	Complete
Used to recharge groundwater	0 - 70%	0 - 10%	Up to 97%
Used in cold climates	Fair ^c	-- ^d	Excellent

a. Percentage of applied water recovered depends upon recovery technique and the climate.

b. Dependent upon crop uptake.

c. Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

d. Insufficient data.

Once a suitable design has been selected and implemented, it should be evaluated with respect to the original objective and design projections. This information could be useful in the future design of similar land treatment facilities.

Environmental impact assessment reports may play an important role in the development or expansion of a food processing plant. Environmental impact assessment reports are intended to provide the public and the government with an overview of the proposed development. Appendix III provides guidelines for the preparation of an environmental impact statement.

1.3 Manual Format

Sections 2, 3, and 4 discuss the variables which are pertinent to system design. Each variable is defined, limiting values are given where applicable and methods of measurement or calculation are described.

Sections 5 and 6 describe detailed process designs for each method of land treatment. Laboratory experiments, pilot studies and lysimeter studies can be used to quantify some of the design variables and to assess process feasibility prior to detailed design. These predesign activities are discussed in Section 5. The design descriptions in Section 6 are supplemented by a design example to illustrate the procedure.

Section 7 describes methods of calculating capital, operating and maintenance costs for a land treatment system, and Section 8 summarizes those constraints which may be imposed on the design or operation of a facility.

In order to assess land application as an alternative for food processing wastewater in Canada and to obtain useful design and operational data from past experience, 15 food processing plants using land application facilities were visited. Much useful information regarding the operation of these facilities was gained from these visits. The findings from these visits are discussed in Section 9 and summarized in Appendix V.

2 SOIL-PLANT SYSTEM CHARACTERISTICS

2.1 Soil Characteristics

2.1.1 Introduction

The purpose of this section is to discuss those physical, chemical and biological soil characteristics which are important in the design of land application systems.

The term soil as used in this manual refers to the vertical section of a landscape which extends from the surface down to bedrock (known as the "regolith"). Soil is composed of mineral particles derived from rocks and decayed organic matter or humus resulting from the microbial breakdown of dead plant and animal tissue. The pore spaces or interstices which typically comprise roughly 50% of the soil volume are filled with a combination of air and water.

Many complex processes take place to change the characteristics of wastewater applied to a soil. These processes can be divided into three principal groups: physical, chemical and biological.

Physical processes. Filtering or retention of solids close to the soil surface is the major physical activity and is a vital part of waste treatment. The size of particles removed from the waste stream is a function of the size and configuration of the pore space of the soil and the nature of the particles in the wastewater. The larger suspended solids are removed from the wastewater but bacteria and viruses can travel considerable distances through soils. It should be pointed out, however, that overloading with suspended material or the creation of anaerobic conditions may have adverse effects on the hydraulic capacity of the system.

Dilution is not strictly a treatment process but may result in a reduction in concentration of the pollutants in humid areas where natural precipitation greatly exceeds the rate of wastewater application. In areas of high moisture deficits where the proportion of rainfall compared to applied wastewater is very small, the dilution effect is insignificant and increased concentrations of chemicals in the soil water may result through evaporation.

The relative importance of soil physical processes in wastewater treatment and removal is a function of the land-application technique:

1. For overland flow methods of wastewater treatment, the soils are usually quite impermeable and very little wastewater infiltration results. Filtering of solids at the soil surface and dilution of the wastewater are therefore minimal.
2. In irrigation systems, water removal by the soil physical processes is as important as the chemical and biological processes also taking place.
3. In infiltration percolation systems, filtration of suspended organic matter from the wastewater is a very important wastewater renovation process. Dilution may also be an important factor for infiltration percolation systems in humid areas.

Chemical processes. Adsorption and chemical precipitation are the two chemical processes occurring in soil resulting in changes in the wastewater quality.

The principal adsorption reaction is associated with the cation exchange capacity (CEC) of soils. Soils containing clay or organic matter attract and retain ions possessing a positive charge (cations). The predominance of an adsorbed ion species is largely determined by its concentration in solution.

The ability of the soil to adsorb cations is important to agricultural production and wastewater treatment. For example, potassium is held on the soil and is made available for plant nutrition rather than rapidly leaching through the root zone. Ammonia behaves in a similar manner and is available for use directly by plants. However, ammonia is rapidly converted to nitrate which may enter the groundwater system.

The ratio of the quantities of the various ions adsorbed on the soil has a major effect on soil structure (sodium adsorption ratio for example). These aspects are discussed in several other sections of this manual.

Certain metal ions retained in the soil may be displaced by metal ions in the wastewater given the right chemical conditions. The displaced ion can be temporarily retained by the soil at a lower depth and gradually migrate to the groundwater, or may react with other ions to form a relatively insoluble compound and be removed from the soil-water system.

Another adsorption phenomenon that likely takes place in soil is the attraction of some gases and organic molecules to soil constituents. Although this type of adsorption is seldom considered in waste treatment discussions, it may be important from the point of view of odour control and the retention of hydrocarbons and biocides.

Chemical precipitation reactions involving dissolved ions and other chemical compounds are numerous and exceedingly complex but are very important in the application of wastes to soil. Calcareous soils, common in the prairies or in limestone-derived soils can neutralize acidic wastes; however, a relatively soluble salt may be produced and result in increased concentrations in the soil solution. For example, high concentrations of carbonate, bicarbonate, fluoride and sulphate, in contact with a soil solution high in calcium can result in the precipitation of these ions. Fluorides can also be removed from solution through the formation of insoluble fluoride salts.

The retention of phosphorus by soils is an important consideration with respect to wastewater irrigation. Two aspects should be considered~

- 1) the residual phosphorus concentration in the soil solution prior to irrigation, and
- 2) the phosphorus adsorbing capacity of the given soil.

Phosphorus is found in conjunction with iron, aluminum and calcium. These compounds are slightly soluble in water. An estimate of the capacity of the soil to adsorb phosphorus may be obtained from laboratory experiments.

The oxygen regime of soils is important with respect to phosphate precipitates. A number of studies have shown that if a soil system is subjected to anaerobic conditions, the phosphorus is released as a soluble salt.

Biological transformation. Some of the groups of soil organisms involved in the decomposition of plant and animal materials are bacteria, fungi, actinomycetes, protozoa, worms and insect larvae. These organisms alter waste constituents and a high proportion of the chemical constituents, notably carbon, nitrogen, phosphorus and potassium, are liberated for plant growth.

Aerobic decomposition of new organic material may be considered to take place in three stages:

1. Organisms initially digest the more easily decomposed material, consuming oxygen and releasing carbon dioxide and water. The amount of oxygen consumed can be estimated by the five-day biochemical oxygen demand test. Organism growth rate is rapid during this stage.
2. The number of organisms declines as the readily decomposed organic material is consumed. The dead microbial tissue, together with the intermediate decay products provide substrate for new and remaining organisms. This material, together with the more refractory organics in the wastewater are degraded to a relatively stable end product known as humus.
3. The organisms decline to population levels similar to those before addition of the wastewater. However, decomposition of humus by highly specialized organisms continues during this phase.

The rate of organic matter decomposition and the nature of the intermediate and end products depend on the composition of the organic matter. Soil factors, however, also exert considerable influence. The presence or absence of adequate oxygen in the soil is the principal factor in determining the rate of decomposition and the end products.

Decomposition also occurs under anaerobic conditions but at a slower rate and often with the production of intermediate compounds having objectionable odours. Plant growth will likely suffer under prolonged anaerobic conditions. Intermittent or partial anaerobic conditions may result in the production of nitrogen gas and various other gaseous oxides of nitrogen. This reaction and the volatilization of ammonia can reduce problems of nitrogen overloading to some extent.

Proteins are hydrolyzed to polypeptides, amino acids and other nitrogenous derivatives, with the final product being ammonia. When residues contain more than 1.5 to 1.7% nitrogen, significant quantities of ammonia are produced. Ammonia in excess of that required for microorganisms and plants is converted first to nitrite and then to nitrate. When residues contain less than 1.5% nitrogen, little ammonia is liberated for plant growth but is reassimilated by microorganisms present.

2.1.2 Definition and functional role of each design variable

There are several physical characteristics which affect the ability of soil to renovate wastewaters and which dictate the type of treatment system. These include permeability, infiltration, available water capacity, cation exchange capacity, and depth to groundwater.

Pore space. Pore space is controlled by the size and shape of the mineral particles and by the quantity of organic matter present in the soil. The size distribution of soil particles is described by texture. Soils are divided into textural classes based on the relative amounts of sand, silt and clay according to the textural triangle given in Figure 3.

1. Sandy soils are those in which sand makes up at least 70% of the material by weight.
2. Clay soil must contain at least 35% clay.
3. Loamy soils lie between these extremes.

Soil structure refers to the organization of individual particles into clumps or aggregates. Sandy soils tend to be relatively structureless, particularly below the surface layer. As the percentages of silt and clay increase, however, aggregation occurs, forming units that range from weak to stable, small to large, and simple to complex. The presence of organic matter strongly favours the formation of stable aggregates. Figure 4 illustrates common soil structural classification. As discussed previously, soil structure may be adversely affected by wastewater characteristics.

Soil texture and structure greatly influence important design variables such as permeability, infiltration, available water capacity and cation exchange capacity.

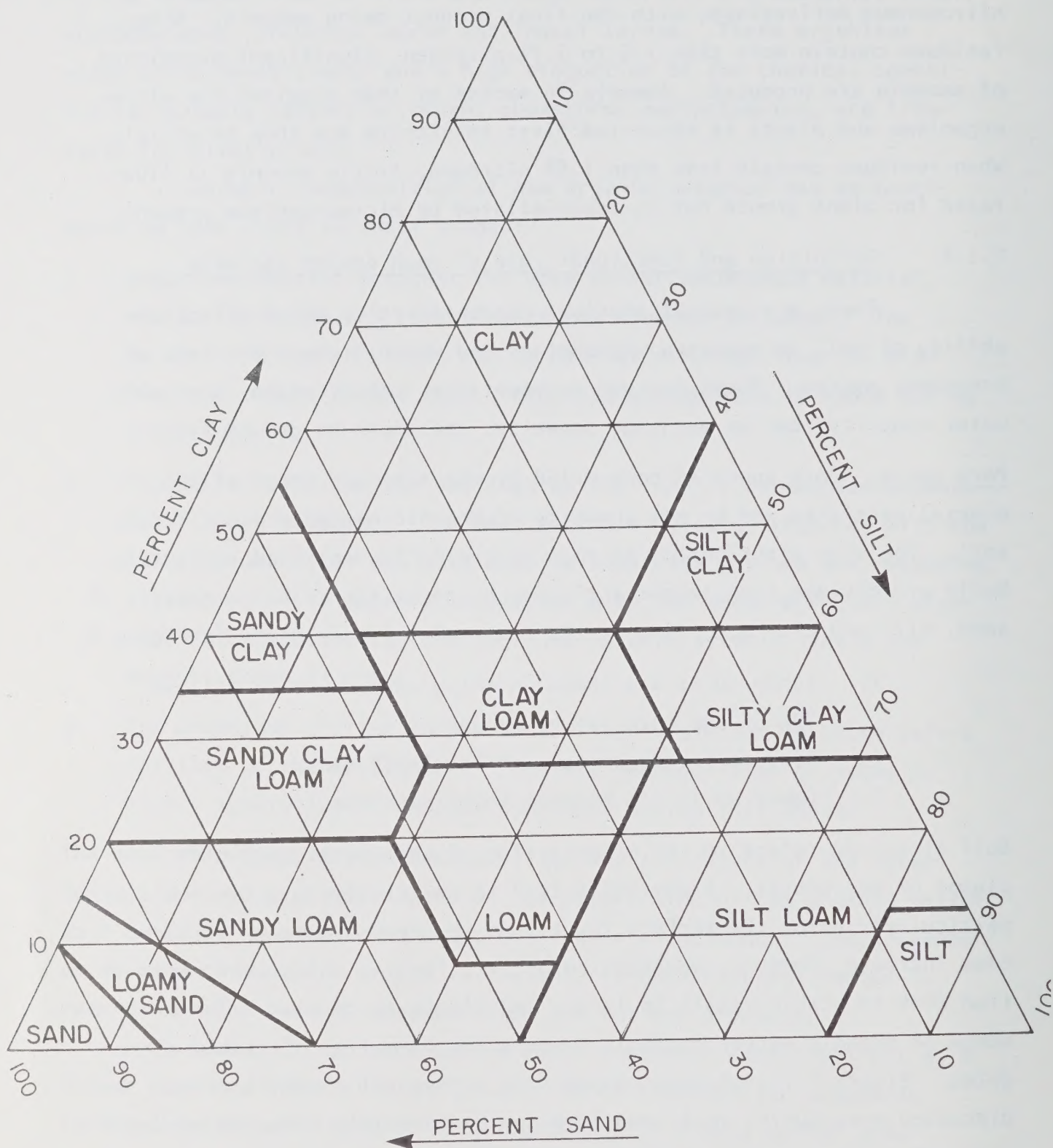


FIGURE 3. PROPORTIONS OF SAND, SILT AND CLAY FOR DIFFERENT SOIL TEXTURES [49]

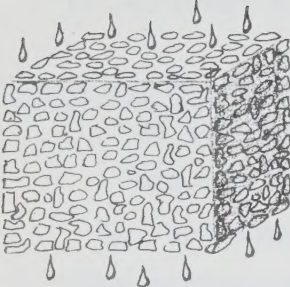
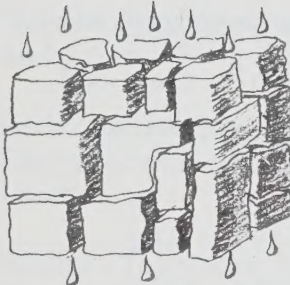
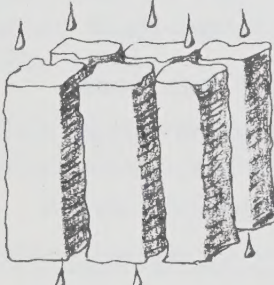
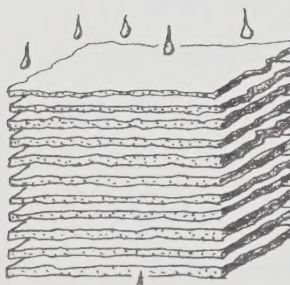
STRUCTURAL TYPE	OCCURRENCE	GENERAL INFLUENCE ON SURFACE TRANSMISSION
	SURFACE HORIZONS	ENCOURAGES
	SUB - SURFACE HORIZONS	RESTRICTS
	SUB - SURFACE HORIZONS	RESTRICTS
	SURFACE OR SUB - SURFACE HORIZONS	SEVERELY RESTRICTS

FIGURE 4. COMMON SOIL STRUCTURAL TYPES [50].

Depth to groundwater. The depth to groundwater is an important variable in the choice of method of land application as well as in the operation of the system. Wastewater treatment capacity is partially a function of depth of available soil.

Permeability. Permeability describes the rate at which water and air move through the subsoil. It is controlled both by soil texture and structure and is primarily a function of pore size. Fine textured and structured soils generally possess low permeability; medium texture and structured soils such as loam or silty loam tend to have moderate to low permeability. Coarse sands exhibit the highest permeability.

Permeability may be quantified in terms of the rate of water movement through a unit cross section of saturated soil in unit time and is commonly expressed in cm/hr. Typical permeability ranges according to soil textural classes are given in Table 2.

Those soils having severely restricted permeability in the lower part of the profile are likely to develop a perched water table and tile drains may be required. Soils having large pores or fractures transmit water and air rapidly but may also transmit contaminants.

Conditions of extreme impermeability in the subsoil horizon may result from layers of impervious clay beds or rock formations located within several feet of the soil surface.

Infiltration rate. Infiltration rate is a soil surface phenomenon which describes the rate of water movement into the soil surface. It is a direct function of pore size and soil moisture content.

During the initial wastewater application, the application rate is controlled by the infiltration rate. The infiltration rate decreases, however, as application continues and approaches a limiting value. At saturation, this constant is equal to the permeability of the least permeable soil layer.

Most screening of suspended material from wastewater occurs during infiltration. However, the high concentrations of suspended solids present in some food processing wastewaters may clog surface soil pores. Thus wastewater pretreatment for suspended solids removal or site management involving periodic tillage to disturb the soil surface

TABLE 2 TYPICAL RANGES OF PERMEABILITY AND AVAILABLE WATER
CAPACITY ACCORDING TO SOIL TEXTURAL CLASS [1]

	Permeability (cm/hr)			Available Water Capacity
	0 to 3%	3 to 9%	greater than 9%	(cm/m)
Very Coarse Texture Sand and Fine Sands	2.5 or greater	2 or greater	1 or greater	4 to 8
Coarse Textured Loamy Sands and Loamy Fine Sands	2 to 4	1 to 2.5	1 to 2	6 to 10
Moderately Coarse Textured Sandy Loams and Fine Sandy Loams	1 to 2.5	1 to 2	.8 to 1	10 to 15
Medium Textured Very Fine Sandy Loam, Loams and Silt Loams	.8 to 2	.5 to 1	.4 to .8	13 to 20
Moderately Fine Textured Sandy Clay Loams and Silty Clay Loams	.5 to 1	.4 to .6	.3 to .4	15 to 20
Fine Textured Sandy Clays, Silty Clays and Clays	.3 to .5	.3 to .4	less than .3	13 to 20

may be required. Application of wastewater at rates beyond the infiltration rate for long periods of time results in anaerobic conditions which may cause clogging.

Compaction of the soil surface by water droplets in a spray irrigation system may greatly reduce pore space volume and seal the surface to downward movement. The presence of a cover crop to cushion the impact of water droplets usually alleviates this problem.

Infiltration rate is an important variable in irrigation and infiltration percolation systems. Wastewater application rates which exceed infiltration rates and thus produce ponding or surface runoff should be avoided. Periods of wastewater application should be followed by rest periods to allow the surface to dry and prevent the persistence of the anaerobic conditions which give rise to surface clogging.

It is emphasized that infiltration rates and soil permeability are the most important considerations in the selection of methods for wastewater treatment:

1. Soils with high infiltration rates are suitable for infiltration percolation wastewater treatment.
2. Soils exhibiting very low infiltration rates can only support overland flow systems.
3. Soils exhibiting moderate infiltration rates are suitable for irrigation systems.

Available water capacity. The available water capacity depends on pore size and shape and the strength of bonding of the water to the soil. It is defined as the amount of water retained by a soil between the field capacity and the wilting point.

Soils can be divided into three groups, depending on the texture (typical ranges of available water capacity are given in Table 2):

1. Coarse texture - low water capacity because of large pores and low surface area; readily drained by gravity.
2. Medium texture - high available water capacity with relatively small pores and medium retention of water.

3. Fine texture - low available capacity due to large surface areas and tightly bonded water.

Available water capacity is very important in the design of a wastewater irrigation system since it influences the type and operation of the selected irrigation system. The available water capacity determines the quantity of water which can be stored in the soil for uptake by plant roots. In addition, the magnitude reflects the amount of wastewater that can be held in the soil without being discharged to the groundwater.

Cation exchange capacity. Cation exchange capacity is a measure of the ability of a soil to retain positively charged ions such as the ammonium ion, calcium, magnesium, potassium and sodium. Both the clay and humus fractions of the soil are characterized by extremely small particle size and by the presence of a negative electrical charge. The significance of this charge is that oppositely charged ions or compounds are attracted and held to these colloidal surfaces. The size of the soil colloids and the magnitude of the electrical charge determine the cation exchange capacity of a soil.

The cation exchange capacity serves as a rough index of reactions which occur between pollutants and the soil surfaces. In general, the greater the cation exchange capacity of a soil, the greater the potential for effective waste treatment.

Cation exchange capacity varies markedly with organic content of the soil and the quantity and type of soil present. Values for a number of materials are given in Table 3. Inspection of this table shows the cation exchange capacity ranges from 4 millequivalents per 100 millilitres (meq/100 ml) for hydrous oxide clays to 200 meq/100 ml for humus.

Groundwater table. The groundwater table is the level in the soil at which free water is present. Above this level, free water movement is vertically downward. At the groundwater table the soil becomes saturated and water movement becomes vertical and lateral.

TABLE 3 VALUES OF CATION EXCHANGE CAPACITY [2]

Material	Cation Exchange Capacity (meq/100 ml)
Hydrous oxide clays	4
Kaolinite	8
Chlorite	30
Montmorillonite	100
Vermiculite	150
Humus	200

The depth of the soil to groundwater is a major factor in determining water storage, and hence the surface water removal capacity of a land application system. In addition, it determines the distance the wastewater will travel through the aerobic zone where potential contaminants can be filtered out or removed by biological and chemical mechanisms before the groundwater is reached.

The variation of depth to groundwater throughout the site and variation with season should be determined prior to the selection of the site and the land application method. In order to ensure an aerobic root zone for cover crop growth, it is preferable to maintain a groundwater level at least five feet below the ground surface. Groundwater levels can be controlled by installing an underdrainage system or by pumping water from wells located close to the site.

2.1.3 Determination of variables

Several methods are available to determine the parameters identified above and these are now discussed. Additional information on procedural details is referenced at appropriate points in the discussion.

Permeability. Permeability is determined from experimental measurements of soil hydraulic conductivity [3].

Hydraulic conductivity can be determined by the auger hole method, above or below the water table. The dry auger hole method (for use above the water table) is recommended for use in the design of land application systems. The method is simple to carry out but is time

consuming. An auger hole is dug and partially filled with water. The water level is kept constant and the rate of loss recorded until equilibrium is established. The final value gives the horizontal permeability of the most permeable layer. A detailed methodology is given in "Methods of Soil Analysis" [3].

The permeameter method [3] can be used to measure the permeability of a specific layer. A large hole is made into the layer and a cylinder driven into it. A constant water level is maintained inside and outside the cylinder and tensiometers are placed outside the cylinder. When the tensiometers indicate zero tension, saturation is assumed, and the test is concluded. The final readings give the expected vertical rate of flow through a specific layer.

Infiltration. The double cylinder infiltrometer is used to determine infiltration rates. The equipment and procedure are similar to the permeameter method described previously except that the outside border is a metal ring rather than the side of the hole. The inside cylinder, at least 30 cm in diameter, is driven into the soil to a depth of 10 cm; the outside cylinder, at least 20 cm larger in diameter, is driven into the soil to approximately the same depth. Both cylinders are kept filled with wastewater. The rate of water loss is measured in the inner cylinder. Details are provided in "Methods of Soil Analysis" [3].

It must be pointed out that the system design should be based on values less than those obtained by this method since the test results tend to be higher than those obtained from a full scale unit. In addition, the design values should take account of a reduction in infiltration rate which may occur after a period of operation due to pore clogging.

Available water capacity. Available water capacity is defined as the difference between field capacity and wilting point measurements. The most accurate values are determined from field and growth chamber experiments but these are very time consuming. More rapid methods are in current use to obtain approximate values for this parameter.

Air pressure is used to simulate the tension associated with field capacity and wilting point. For all practical purposes, the 1/5 atmosphere percentage using a pressure plate apparatus is generally

accepted as an index of the wilting point. The upper limit for the range of soil water available to plants is much more difficult to establish. However, many laboratories use the 1/3 atmosphere percentage for the determination of the upper moisture limit for fine and medium textured soils, and a 1/10 atmosphere percentage for coarse textured soils.

A more detailed discussion including experimental procedure is given in the Agriculture Handbook 60 [4].

Cation exchange capacity. The methods used to determine cation exchange capacity generally give only order of magnitude values. In addition, the values obtained are dependent on the procedure used.

Most investigators saturate the exchange complex with a given cation, remove the excess by washing with alcohol, displace the first cation by a second cation and determine the concentration of the first cation using an appropriate analytical method. Details of this procedure are given in the Agriculture Handbook No. 60 [4] and "Methods of Soil Analysis" [3].

Groundwater levels. Groundwater levels can be determined by installation of observation wells, and groundwater flow characteristics are determined from piezometers installed on-site.

2.1.4 Summary

A summary of the major soil characteristics is given in Table 4. Methods of determining these characteristics are listed for convenience. Those variables on which the characteristics depend are also given in Table 4. Reference is made to Tables 2 and 3 for typical values of these soil characteristics.

2.2 Plant Characteristics

2.2.1 Introduction

It was pointed out that successful waste treatment by land application depends on three major factors:

- 1) wastewater characteristics,
- 2) climatic characteristics,

TABLE 4 SUMMARY OF SOIL CHARACTERISTICS

Characteristic	Secondary Variable	Method of Determining Primary Variable	Ref
Permeability	Texture Structure Presence of restricting layers	Auger - hole method permeameter method	[3]
Infiltration Rate	Texture Moisture content Surface conditions	Double-cylinder infiltrrometer	[3]
Available Water Capacity	Texture Structure Soil-particle surface tension	Field and growth chamber experiments Pressure-plate apparatus	[4]
Cation Exchange Capacity	Texture Organic-matter content Clay mineralogy	Cation saturation	[3]
Groundwater Table		Well	
Groundwater Flow		Piezometer	

3) soil/plant characteristics.

The purpose of this subsection is to define the role played by the cover crop in wastewater treatment, the major design variables and the cover crop alternatives.

Vegetation increases the capacity of soil to accept and treat wastes by several methods. Rooted plants protect the soil from loss by erosion, encourage and maintain moisture infiltration, increase soil drying rates through transpiration, and absorb nutrients. Vegetative cover also has an aesthetic appeal and may contribute an economic benefit through crop harvest and sale.

2.2.2 Mechanisms of wastewater treatment

Increased soil infiltration rates. The capacity of a land application system to accept moisture is increased by the presence of a cover crop.

The rate of application of liquid is controlled by the rate at which the applied water enters the soil system. The moisture infiltration rate is greatly influenced by compaction caused by the direct impact of water droplets on bare ground. Vegetative cover and decaying plant residues act as cushions, absorbing the impact energy of water droplets. In addition, decaying organic matter and plant roots encourage granular structure in the soil, thereby increasing the pore space, particularly in fine textured soils.

Through the presence of roots and decaying plant residues, vegetation also affects soil freezing. Bare or compacted soils, low in organic matter, tend to form a solid mass when frozen. In contrast, granular soils, high in organic matter, retain their porosity on freezing, thus freely accept water. For example, some frozen soils have infiltration rates equal to or greater than values for unfrozen soil [5].

Vegetative cover also inhibits soil erosion losses through surface runoff.

Water removal. Aerobic conditions are necessary for rapid decomposition of organic matter and for the control of potentially offensive odours; therefore, the treatment site usually requires a resting period to allow the soil to drain and reaerate. Some water is lost by evaporation from the soil during these periods; these losses are confined to water at or near the soil surface.

Plants provide an additional means for water removal up to several feet below the surface. Water moves into the plant roots and upwards to the plant body where moisture is lost from the leaves by transpiration. The transpiration rate is a function of climatic conditions including temperature, precipitation, solar radiation and wind. It also depends on the availability of soil moisture and on such characteristics as rooting depth and the seasonal pattern of root and leaf development.

It is generally not feasible to quantify evaporation and transpiration separately; therefore, a combined value (evapotranspiration rate) is used for design purposes.

Nutrient removal. Food processing wastewater effluents contain most of the essential nutrients for plant growth, though not necessarily in balanced proportions. Two of these nutrients, nitrogen and phosphorus, are of particular concern in wastewater renovation because of their relationship to eutrophication of surface waters.

Vegetation utilizes a portion of these nutrients for growth, the quantity removed being variable and dependent on plant type and the harvested yield. The relative importance of nutrient uptake by vegetation in a particular system depends on the treatment system and the wastewater characteristics.

2.2.3 Design Variables

The following cover crop design variables are important in the selection of a land application system:

- 1) water requirements,
- 2) nutrient requirements,
- 3) tolerance of the plant to potentially harmful waste characteristics,
- 4) market value of the crop,
- 5) management requirements of the cover crop.

These design variables are now discussed with a summary presented at the end of this section in Table 6.

Water requirements. The amount of water which the cover crop is able to remove through evapotranspiration limits the hydraulic loading on the plant-soil system.

It was pointed out earlier that evapotranspiration is a function of the cover crop as well as climatic conditions. Important evapotranspiration factors associated with the cover crop include rooting depth, seasonal pattern of root and leaf development and other specific factors such as the physical nature and size of leaf growth.

Rooting depth increases in importance as the length of the resting period in the wastewater application schedule increases. As the surface layer of the soil dries, water will be drawn from successively greater depths. Plants such as alfalfa with deep rooting systems can

also penetrate impermeable subsoil zones and thus increase the water infiltration capacity of the soil.

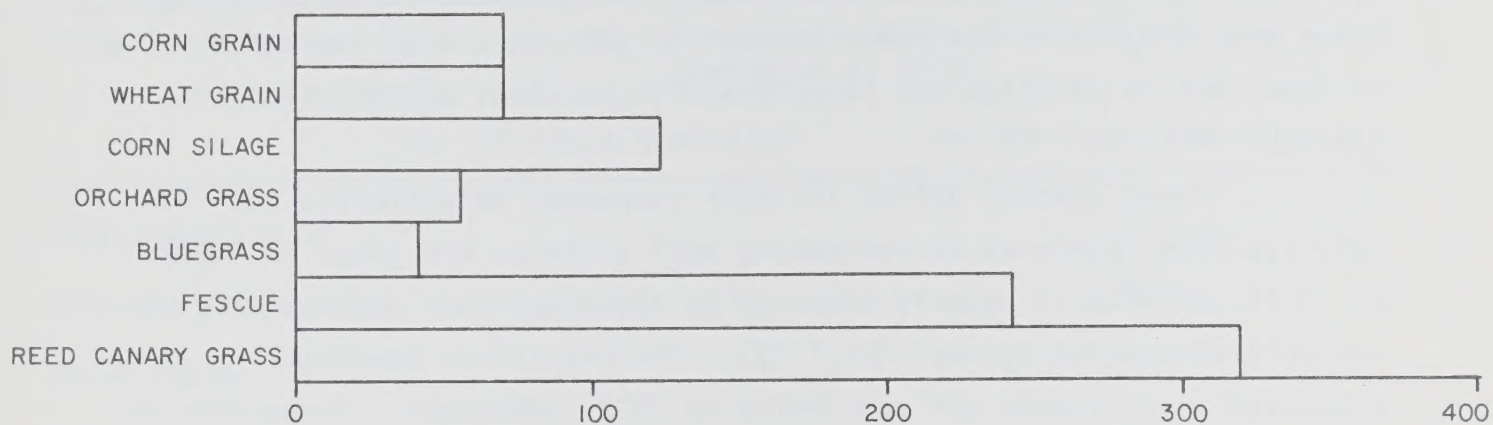
Plants develop most of their roots in and derive most of their moisture supplies from the upper portions of the root zone. For most plants these "effective rooting depths" are probably less than one-half or possibly two-thirds, of the maximum depths of root development. The following are typical effective rooting depths for commonly irrigated crops [6]:

- 1) pasture grasses - 60 to 75 cm,
- 2) cereal grains - 90 cm,
- 3) red clover - 60 cm,
- 4) alfalfa - 90 to 180 cm,
- 5) field corn - 190 cm,
- 6) vegetable crops including peas, beans, potatoes, beets, carrots and tomatoes - 45 to 75 cm.

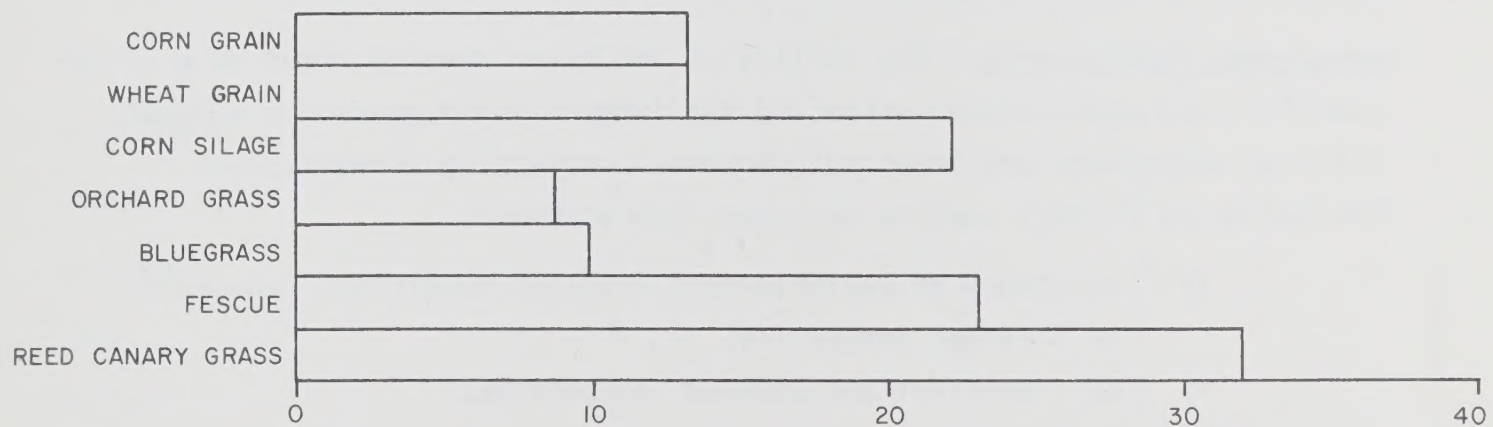
Seasonal patterns of vegetation development and transpiration differ among various crop plants. These aspects are discussed under "cover crop alternatives" later in this section.

Nutrient requirements. Nutrient removal through crop harvest is the primary mechanism of nitrogen and phosphorus removal from the soil and depends on the type of land application system. For example, in an overland flow system, both nitrogen uptake and denitrification play major roles in nitrogen removal. Phosphorus removal, however, is determined by plant uptake since adsorption by the soil is not significant. In contrast, the quantity of nutrients removed by plants may be minor compared to total loadings in an infiltration-percolation system.

The quantity of nutrients which can be removed depends on the type of plant cover and the harvested yield. Figure 5 illustrates the potential for removal of nitrogen and phosphorus in various crops. Both nitrogen and phosphorus are absorbed in greatest quantities by certain species of grasses. Harvesting the entire cover crop (for example, corn silage, hay) results in greater nutrient removal than harvesting only selected parts (grain, vegetable crops) and ploughing the remaining vegetation into the soil.



NITROGEN REMOVED IN HARVEST (kg/ha-yr.)



PHOSPHORUS REMOVED IN HARVEST (kg/ha-yr.)

FIGURE 5. POTENTIAL NUTRIENT REMOVAL BY CROPS.

Tolerance to toxicity. Certain chemical constituents of wastewater may be toxic to vegetative growth. The elements of possible concern in food processing wastewaters include sodium, calcium and magnesium, and various salts such as chloride, sulphate and bicarbonate.

The effect of saline solution on plant growth is principally due to changes in the osmotic pressure of the solution, which influences water availability to the plant roots. In addition, high concentration of ions such as chloride may interfere with nutrient assimilation by plants.

Plant species differ in their responses to salinity; the relative crop responses to increasing soil salinity are given in Table 5. Soil salinity is usually measured by the electrical conductivity of the soil saturation extract (EC_e) [3]. The electrical conductivity is expressed in millimhos per centimetre at 25°C (mmhos/cm). Inspection of Table 5 shows that the soil salinity giving a 50% reduction in yield can range from 4 mmhos/cm to 18 mmhos/cm for beans and grasses, respectively.

In addition to possible crop damage from increased soil salinity, Melsted [9] has suggested that direct damage to plant leaves from spray solution is likely to occur when the electrical conductivity of the water reaches 4 mmhos/cm.

Management requirements. The ability of the cover crop to adapt to a specific land application system and the labour requirements for successful crop management are important factors in selecting a cover crop. The following factors need to be taken into account:

- 1) tolerance to variable soil moisture conditions, especially frequent saturation,
- 2) soil physical and chemical properties,
- 3) tolerance to severe climatic changes such as low temperatures and the plant growing season.

Assistance in the selection of crops can normally be obtained from local agricultural representatives.

Labour requirements for successful crop management may be critical during all stages of crop growth. These include germination,

TABLE 5 CROP RESPONSES TO SOIL SALINITY [8]

Crop	Electrical Conductivity EC _e (mmhos/cm at 25°C)	
	At 10% Yield Reduction	At 50% Yield Reduction
Tall Wheatgrass	11	18
Crested Wheatgrass	6	18
Tall Fescue	7	15
Perennial Rye	8	13
Birdsfoot - Trefoil	6	10
Alfalfa	4	9
Orchardgrass	3	9
Clovers (Alsike & red)	2	4
Barley	12	18
Sugarbeets	11	17
Wheat	7	14
Soybean	6	9
Corn	6	7
Beans	2	4

emergence, and seedling establishment, in which favourable soil and moisture conditions are critical for some crops.

During the growth period, important management factors may include supplemental fertilization, well defined tillage practices, irrigation scheduling, weed and insect control and crop harvesting. It may also be necessary to re-establish or rotate crops from time to time when visual checks or yield tests indicate poor productivity. Specific cover crop requirements and limitations are discussed later in this section.

Market value. The economic return from certain crops may offset some of the operating costs of a land application system. The return may be substantial in arid regions because the availability of water permits the growth of crops not otherwise possible. In such area, limited competition in local markets may add significantly to this monetary return.

The economic benefits may, however, be offset by added constraints. In a land treatment system whose dual objectives are wastewater treatment and crop harvest and sale, management costs will be higher and site flexibility lower than in a system where the sole objective is wastewater treatment and removal. Machinery and labour are required to seed, cultivate, harvest and market the crop. In addition, irrigation will need to be scheduled to accomodate optimum growth conditions and not necessarily to provide maximum efficiency in wastewater removal.

2.2.4 Cover crop alternatives

The following cover crop alternatives have been used in land application systems:

- 1) small grains,
- 2) row crops,
- 3) sod crops,
- 4) forest land.

These alternatives are now discussed in detail.

Small grains. Small grains include wheat, barley and oats. These crops provide one means of cost recovery. They have several limitations in land application systems. They are not very tolerant to excess water and nutrients, and stem weakness or breakage results in "lodging" of some of these crops when excess nitrogen is applied. In addition, excess water and nutrients may also create uncontrollable weed problems. At certain times of the growing season, vehicular access to spraying equipment, etc. may be disrupted, affecting maintenance.

A high degree of management is required at all stages of production, including annual land preparation, seeding, weed control and harvesting. Nutrient and water removal by small grain crops are minimal due to the short active growth season. Therefore, for optimum nutrients and water removal, large areas of land are usually required for irrigation and large reservoirs may be required for off-season storage. Small grains may, however, be used successfully as a nurse crop for perennial crop establishment.

Row crops. Row crops include corn and sugar beets. These crops, like small grains, provide a means of cost recovery for the land application system. When the entire above ground portion of the crop is harvested, as in the case of corn for silage, maximum nutrient removal is realized. Row crops are also more adaptable to on-site traffic than small grain crops.

Like the small grains, water and nutrient removal by row crops is limited to the time period between crop establishment and crop maturity. In addition, the spaces between the rows may act as water conduits; thus row crops are not suited to overland flow or rapid infiltration systems.

Sod crops. Sod crops include legumes and grasses. They are most frequently used as cover crop and may be managed by frequent mowing or cutting for hay, green feed or silage to minimize growth. Sod crops offer the following advantages:

- 1) competitive with natural vegetation and weeds on a growth basis,
- 2) good utilization of plant nutrients (Figure 4),
- 3) tolerant to wet conditions,

- 4) relatively successful on poorer soils,
- 5) excellent erosion control,
- 6) longer periods of active growth than small grains and row crops,
- 7) improvement in soil structure and enhancement of water transmission and soil aeration capabilities,
- 8) ability to withstand heavy vehicle traffic,
- 9) cold weather hardiness.

The longer growing season results in increased water consumption. As a result, acreage and winter storage requirements are usually lower than those for small grains and row crops.

Figure 6 illustrates a typical land application facility using a grass cover crop.



FIGURE 6. USE OF A SOD CROP FOR FOOD PROCESSING WASTEWATER RENOVATION AND REMOVAL.

Grasses such as Reed Canary, Brome, Timothy, Fescue, Perennial Rye and Orchard are frequently used cover crops. They are more tolerant than legumes which, in general, do not tolerate frequent flooding and frequent heavy vehicle traffic. Legumes are also susceptible to winter killing through ice smothering and soil heaving. Grass crops, however, are usually much less palatable than legumes as livestock feeds. Forage mixtures of legumes and grasses combine the benefits of both crops and thus create an easily manageable and marketable cover crop.

Vegetable crops. Vegetable crops such as sweet corn, beans, and peas may also be used as cover crop. The relatively high management requirements are offset by the potential for high economic return. Land application systems may be operated in conjunction with vegetable processing plants to use the machinery and skilled crop management personnel necessary for raising these crops.

Limitations similar to those for row crops apply to vegetable crops when used as a cover crop. In addition, local regulations may prohibit application of wastewater to crops used for direct human consumption.

Forest land. Forests have the potential for accepting relatively large volumes of wastewater and organic matter. Infiltration rates are typically quite high (15 cm/hr or greater) because of the relatively high porosity of forest soils resulting from the high organic content. The upper mineral soil is highly porous and is protected by vegetation and surface litter against the impact of water drops. The litter layer also furnishes food for organisms which permeate the soil and maintain conditions for water entry. The absence of heavy vehicle traffic and the thick surface litter prevents soil compaction and further enhances infiltration rates.

Forests do not remove large quantities of nutrients, particularly nitrogen. Although the natural uptake of nutrients compares with many agronomic crops, only a small percentage is removed from the area since nutrient-rich leaves, twigs, bark and roots are returned to

the soil. Logging operations remove accumulated nutrients from the forest site but the amounts are low compared with the time required for tree growth.

The forest soils may be the key to the removal of water and excess nutrients. Although it is possible that nitrogen and phosphorus are removed through fixation and denitrification, the significance of these mechanisms has not been determined.

The choice of cover crop and management practice may be determined by wastewater characteristics including volume and nutrient concentrations, length of the growing season, nature of the winter climate and by the soil physical and chemical characteristics. Economic objectives, however, will usually be of secondary importance to maximization of wastewater renovation and removal.

2.2.5 Ancillary benefits of cover crop

There may be several ancillary benefits associated with system economics and aesthetics of the land application systems. Harvesting and sale of cover crops such as grass, cereal grain and vegetables may provide an economic return to offset part of the operating and maintenance expenses. Vegetative cover also has aesthetic value in that the potential appearance of a waste application site may affect its overall acceptance. Managed cropland or forestlands are often judged aesthetically appealing in contrast to weeds or bare soil. Appropriate use and design of vegetative cover are aspects which should be taken into account when considering aesthetic and public acceptance aspects of the land application system.

2.2.6 Summary of plant characteristics

The plant characteristics which should be taken into account and which have been discussed in this section are summarized in Table 6.

TABLE 6 SUMMARY OF PLANT CHARACTERISTICS

Primary Characteristic	Secondary Characteristic	Tertiary Characteristic
Water Requirements	Rooting depth Seasonal pattern of root and leaf development	
Nutrient Requirements	Type of crop Harvested yield	
Tolerance to Toxic Substances		
Market Value		
Management Requirements	Crop adaptation ability	Tolerance to variable soil moisture Tolerance to soil physical and chemical processes Tolerance to adverse climate Growing season length
	Labour requirements	Fertilization requirements Tillage requirements Irrigation requirements Weed and insect control Crop rotation

3 WASTEWATER CHARACTERISTICS

3.1 Introduction

Knowledge of the characteristics of the wastewaters to be applied is critical for the successful design and operation of a land application system. The purpose of this section is to discuss those wastewater characteristics which are important to land application design and operations. In addition, pertinent wastewater characteristics from various food processing industries are given and discussed as they relate to the area of land application. The possible need to pretreat wastewater prior to its discharge to the land is also discussed, where appropriate.

3.2 Wastewater characteristics important to the evaluation, design, and operation of land application systems

Prior to conducting exhaustive site evaluations, consideration should be first given to the quantity and quality of the wastewater to be applied to the land. The wastewater characteristics will, to some degree, affect the land application method chosen and will directly affect its operation.

A detailed characterization is required of those wastewater constituents which may affect or interact with the soil or groundwater. The presence of constituents which could adversely and/or irreversibly affect the soil and groundwater may preclude the use of land application. These particular constituents would have to be effectively and economically removed prior to the application of the wastewater. In addition, pretreatment of the wastewater may be necessary to remove constituents which impair the efficient operation of the land system, but do not necessarily damage the soil or groundwater environment.

The important wastewater characteristics which will generally define the design limitations/parameters of land application systems include the following:

- 1) wastewater flow rates,

- 2) biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD),
- 3) suspended solids (SS),
- 4) total dissolved solids (TDS) and electrical conductivity (EC),
- 5) nitrogen (N),
- 6) phosphorus (P),
- 7) pH,
- 8) temperature,
- 9) color,
- 10) toxic elements (heavy metals, trace elements, etc.),
- 11) bacteria and viruses,
- 12) sodium adsorption ratio (SAR),
- 13) oil and grease.

These parameters are now discussed.

3.2.1 Wastewater flow rates

The quantity of wastewater to be treated by the land application system is an important design parameter and should be determined as accurately as possible. The conditions and characteristics of the soil, climate, and crop will essentially govern or define the liquid loading rate. This rate can be defined as the average amount of wastewater that can be effectively applied to the land over a fixed time period, taking into account the periodic nonapplication of wastewater (land resting period). The liquid loading rate and the quantity of wastewater to be treated are needed to determine the land area required.

The following flow rates should be determined:

- 1) present or initial average flow,
- 2) present peak flows and duration,
- 3) projected future average flows,
- 4) projected future peak flows and expected duration.

Based on the allowable liquid loading rate and the present average flow, the amount of land required for the system can be calculated. The projected average flows, and the liquid loading rate can be used to

determine the total land area that may be required at some future date. Provision could thus be made in the design of the land application facility, and in the acquisition of land, to handle adequately plant expansions without major additions being required for the effluent treatment system.

Instantaneous peak flows (less than an hour in duration) will normally have minimal effect on the system and its design. However, sustained peak flows of two to three hours or more may require special design features, such as storage facilities for flow equalization, higher pumping capacities, etc.

In some food industries such as fruit and vegetable canneries, wastewater flows exhibit seasonal peaks lasting for several months during the harvest season. In such cases, system design may include sufficient land area to handle these peak flows, or the use of effluent holding facilities. The holding facilities would permit equalization in the application rate over an extended period of time.

Some typical liquid/wastewater loading rates for various methods of land application are given below:

- 1) Irrigation - 0.2 to 1.5 cm (0.1 to 0.6 inches) per day,
- 2) Overland flow - 0.6 to 1.8 cm (0.25 to 0.7 inches) per day,
- 3) Infiltration Percolation - greater than 1.5 cm (0.6 inches) per day.

It should be emphasized that the above values are general ranges for loading rates. The limiting wastewater loading rate must be determined for each specific land application site.

3.2.2 Biochemical oxygen demand and chemical oxygen demand (BOD_5 and COD)

Chemical oxygen demand is a measure of the oxidizable organic and inorganic content of a wastewater, while biochemical oxygen demand indicates what portion of the organics are readily biodegradable. The ratio of BOD_5 to COD is a useful parameter in determining the biodegradability of a wastewater and its potential for being treated effectively

by a biological treatment method. The closer the BOD_5 to COD ratio is to unity, the more amenable the wastewater is to biological treatment.

The significance of BOD_5 and COD to land application is the amount of oxygen demanded by these parameters and whether or not the soil environment can satisfy this demand. The peak oxygen demand occurs in the first few days after the application but appreciable demands may persist for subsequent days.

Well designed and operated land application systems will effectively remove both COD and BOD_5 in the applied wastewater. However, there are limits to the amounts of COD and BOD_5 that can be placed on the land over a fixed period of time. In decomposing readily biodegradable organics, the soil microbial population can generate an impermeable layer within the top few inches of soil. This biological clogging is a function of the waste organic material added (BOD_5) and the porosity of the soil. Continued application of wastewater to the land, after biological clogging has occurred, will result in ponding on the soil surface and anaerobic conditions in the soil. It has been shown that under anaerobic conditions, approximately 10% of the BOD_5 load may be removed; the remaining BOD_5 remains mobile and may present a hazard to groundwater [10].

It is very important to maintain aerobic conditions in the soil. Ponding of wastewater should be avoided and rest periods between wastewater applications should be provided for soil reaeration. In addition, a limiting organic (BOD_5) loading rate should be determined for each specific application site. The application and resting schedules should also be determined specifically for each site.

Most food processing wastewaters are readily biodegradable and exhibit a high BOD_5 to COD ratio. Ranges of BOD_5 and COD characteristics observed at existing land treatment systems are as follows:

BOD_5 : 200 to 4,000 mg/L,
COD : 300 to 10,000 mg/L.

Organic loading rates in the range of 40-100 kg/ha/day (40 to 100 lbs/acre/day) have been used successfully for overland flow systems [11], while rates in excess of 660 kg/ha/day (600 lb/acre/day) have been used for infiltration percolation systems.

A common application schedule is one day of application followed by a four to seven day rest period.

3.2.3 Suspended solids (SS)

Suspended solids in wastewater applied to land may cause operational problems such as clogging of sprinkler nozzles and soil pores, and the formation of an impermeable coating over the soil surface. Suspended solids concentrations in the range of 200 to 3,000 mg/L have been applied to the land, without adverse effects, using a variety of systems and operational techniques.

The presence of high concentrations of solids in wastewater should not restrict its application to a soil system. A number of techniques are available for handling suspended solids:

- 1) Suspended material can usually be adequately removed by pretreatment methods such as screening and sedimentation.
- 2) The suspended solids loading rate can be limited to permit microbial decomposition of the suspended material during application and resting periods.
- 3) Periodic tilling of the soil surface can be useful to restore permeability.

3.2.4 Total dissolved solids (TDS) and electrical conductivity (EC_e)

The aggregate of the dissolved compounds in the plant wastewater is the TDS. Most of the TDS are dissolved inorganic salts. An excessive rate of application of high TDS bearing wastewaters may cause salinity hazard to crops and/or may cause groundwater contamination. The salinity hazard to crops can be especially prevalent in arid or semiarid regions where the annual evapotranspiration exceeds the annual precipitation.

The soil does not have the mechanism to remove dissolved solids permanently from the applied wastewater. As a result, these solids either build up in the root zone, resulting in alkaline and saline soils, or they are leached to the groundwater.

Electrical conductivity (EC_e), which is related to the TDS content of the wastewater, is a numerical expression of the ability of a

solution to carry an electric current. A sodium chloride salt (NaCl) solution having a TDS concentration of 640 mg/L will exhibit an electrical conductivity of 1 mmho/cm at 25°C. The EC_e value of wastewaters provides a good indication of the TDS concentration to be expected; the higher the EC_e reading the higher the TDS concentration within the solution. Electrical conductivity can be easily determined.

A general classification of the salinity hazard exerted by the TDS and EC_e of a wastewater, for an arid and semiarid region, is given in Table 7. Inspection of this table shows that no problems are anticipated for TDS values of 500 mg/L or less and electrical conductivity of 0.75 mmhos/cm or less.

TABLE 7 POTENTIAL SALINITY HAZARD OF WASTEWATERS [11]

Degree of Salinity Hazard	TDS (mg/L)	EC (mmhos/cm)
No problems	up to 500	less than 0.75
Some problems anticipated	500 to 2000	0.75 to 3.0
Severe problems	greater than 2000	greater than 3.0

In contrast, severe problems may occur if the level of TDS in the wastewater is greater than 2,000 mg/L or the conductivity is greater than 3.0 mmhos/cm. In regions with adequate rainfall, it is possible that the TDS would be leached to the groundwater regime.

A number of techniques are available to avoid excessive salt build up in the soil zone and excessive leaching to groundwater. Some of these techniques include the following:

- 1) Application of sufficient wastewater to leach the salts deeper into the soil. However, the groundwater would require careful monitoring to determine if any severe contamination, in terms of both TDS and other pollutants present in the effluent, was occurring.
- 2) If the application of the wastewater could potentially increase the TDS levels within receiving groundwater to an unacceptable level

(Canadian Drinking Water Standards specify an objective for TDS of 500 mg/L or less), a subsurface drainage system should be installed to intercept the water prior to its entering the groundwater. It may be necessary to treat the intercepted water for TDS removal prior to its ultimate discharge.

3.2.5 Nitrogen (N)

Nitrogen is an important plant nutrient and when contained in wastewater may be present in any of five forms:

- organic nitrogen
 - ammonium ion (NH_4^+)
 - free ammonia (NH_3)
 - nitrite (NO_2^-)
 - nitrate (NO_3^-)
- } Both exist in aqueous solution, the proportion depending on pH.

The relationships that exist between these forms of nitrogen and the changes that can occur in soil are very important and are best illustrated diagrammatically as shown in Figure 7. With reference to this figure, the nitrogen applied in a land application system can be accounted for as follows:

Decomposition (mineralization). The organic nitrogen contained in the applied wastewater is filtered out by the soil matrix and mineralized (decomposed) into both ammonium ion (NH_4^+) and free ammonia. The ammonium ion is either taken up by the plants, undergoes nitrification or is adsorbed by the soil.

Nitrification. Nitrification is the overall biological oxidation process by which the ammonium ion is oxidized to nitrites followed by the oxidation of the nitrites (NO_2^-) to nitrates (NO_3^-). Nitrate is not retained by the soil, but is either utilized as a nutrient by plants, undergoes denitrification, or is leached to groundwater.

Crop nitrogen uptake. The uptake of nitrates and ammonium ion by plants is an important mechanism for removal of nitrogen from wastewater. Nitrogen removal by crops is dependent on the length of growing season, the type of crop, and the amount of nitrogen available. The nutrient requirements of plants are discussed in greater detail in Section 6.4.3(c).

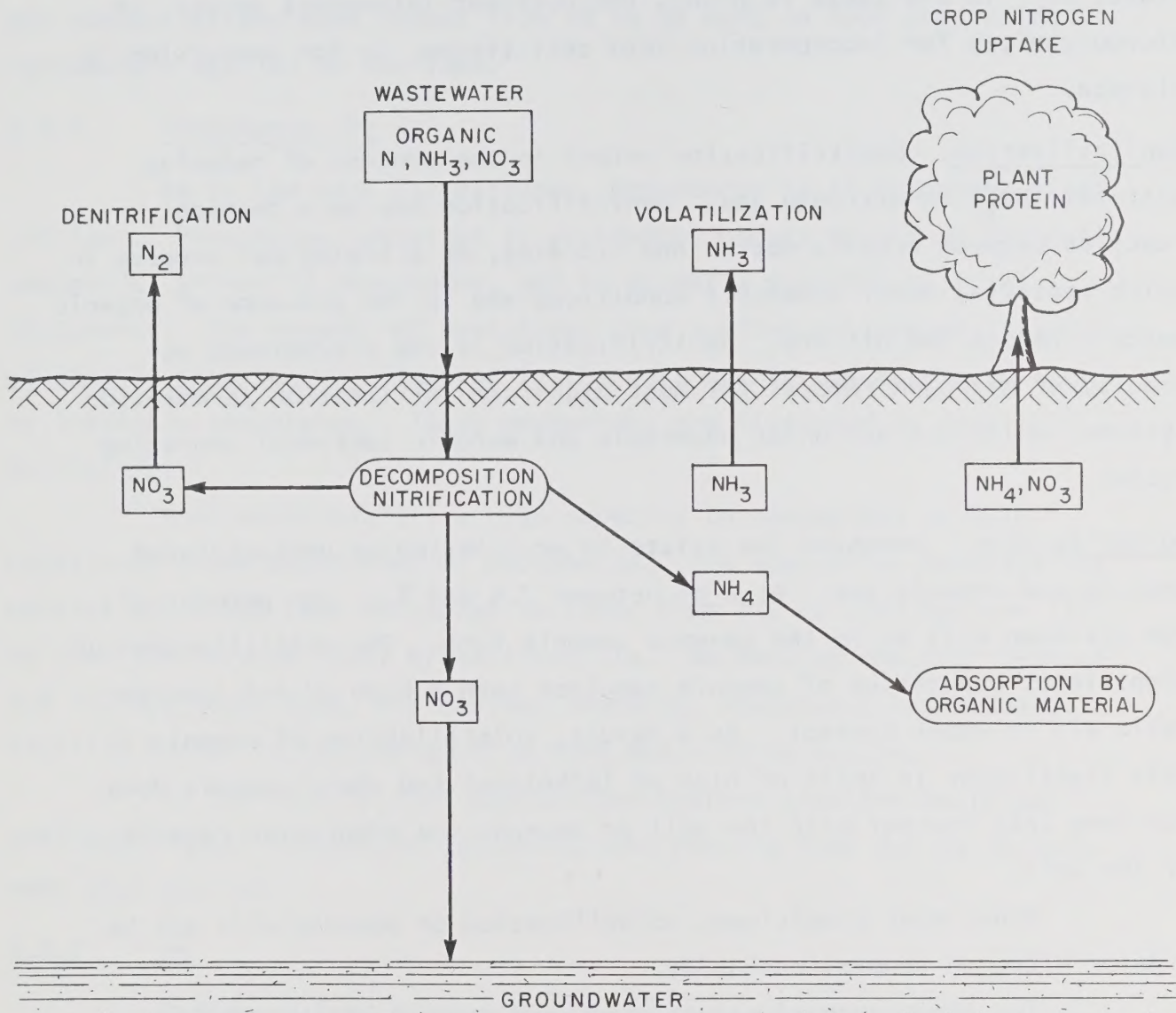


FIGURE 7. NITROGEN CYCLE IN SOIL

Adsorption. In the soil, the ammonium ion participates in various adsorption reactions in soil exchange sites on organic and mineral particles/fractions of the soil. These mechanisms are discussed in Section 5.1.2. In some cases, the adsorbed NH_4^+ ions can be held very tightly and are thus resistant to leaching. While in the adsorbed state, NH_4^+ is available to plants for nutrient (nitrogen) uptake, to microorganisms for incorporation into cell tissue, or for conversion to nitrate.

Denitrification. Denitrification refers to the process of reducing nitrates (NO_3) to nitrogen gas. Denitrification may be a chemical reaction between organic matter and nitrates, or a biological process in which bacteria, under anaerobic conditions and in the presence of organic matter, reduce the nitrate. Denitrification is the predominant mechanism of nitrogen removal for most high-rate infiltration percolation systems, which operate under anaerobic and aerobic (wet-dry) operating cycles.

Volatilization. Ammonium ion exists in equilibrium as undissociated ammonia and ammonia gas. At a pH between 7.5 and 8.0, ten percent of the nitrogen will be in the gaseous ammonia form. The volatilization of significant quantities of ammonia requires both a high pH and considerable air to water contact. As a result, volatilization of ammonia is only significant in soils of high pH (alkaline) and where ammonia does not come into contact with the soil or exceeds the adsorptive capacity of the soil.

Under most conditions, volatilization of ammonia will not be a major nitrogen removal mechanism.

The importance of maintaining good control of the applied nitrogen cannot be overemphasized. The nitrate form of nitrogen cannot be retained in the soil and is very mobile and leaches readily to the groundwater regime. Excessive amounts of nitrates in drinking water contribute to the illness known as infant methemoglobinemia (blue babies) and is known to produce irritation of the mucous membrane of the stomach and urinary bladder. A limit of nitrate plus nitrite of 10 mg/l as nitrogen has been recommended in the Canadian Drinking Water Stan-

dards. In addition, should excess nitrogen be available, some crops can accumulate high levels which may be toxic to livestock and may be toxic to the plant itself.

On an annual basis, the applied nitrogen should be accounted for by crop uptake, denitrification, volatilization, adsorption (storage in soil) and/or addition to groundwater or surface water. Total nitrogen concentrations have ranged from 10 to 50 mg/L in food processing wastewaters applied to the land.

3.2.6 Phosphorus (P)

As is the case for nitrogen, phosphorus is an important plant nutrient. Phosphorus contained in wastewater occurs mainly as inorganic compounds, primarily phosphates, and is normally measured as total phosphorus. The removal of phosphorus from applied wastewater is accomplished by crop intake, fixation in the soil matrix and by precipitation as insoluble phosphates. These mechanisms are discussed in detail in Section 5.1.

Most soils exhibit a high capacity to remove and to hold relatively large quantities of phosphorus. The adsorption capacity for several soils has been estimated to range from 235 to 2720 kg/ha-m (77 to over 900 lb/acre-foot) of soil profile. Because of the high removal and storage capacities, and minimal leaching, phosphorus is seldom a limiting factor in the design of a land application system.

In the case of land application systems treating municipal effluents, total phosphorus concentrations ranging from 2.1 to 16 mg/L have been applied.

3.2.7 pH

The pH of food processing wastewaters exhibits a wide variability from one processing plant to another, and even in the wastewaters being discharged by one specific plant. A wastewater having a pH in the range of 6 to 7 is considered neutral, while acidic and basic solutions usually range in pH from 4 to 6 and from 7 to 9, respectively.

Microbial and plant processes are generally most active in the neutral pH range (6 to 7). Therefore, acidic wastewaters having a pH of

6 or less and basic wastewaters with pH of 9 or more should be adjusted to the neutral range. Wastewater having a pH between 6.0 and 9.0 are generally suitable for application to the land.

3.2.8 Temperature

The application of high temperature wastewaters to the land can sterilize the soil and thus preclude the growth of any vegetation. In general, if the temperature of the wastewater is in excess of 150°F, it should be cooled prior to land application. However, these temperatures are rarely encountered in food processing wastewaters.

3.2.9 Colour

In most wastewaters colour is associated with degradable organic material and is effectively removed as the water percolates through the soil mantle. However, should the colour associated with the wastewater be persistent, such as that associated with lignins, it can leach into the groundwater and effectively contaminate this water source. This type of groundwater contamination is difficult to avoid and therefore coloured wastewaters to be applied to the land should be carefully assessed for ease of colour removal.

3.2.10 Toxic elements

The elements listed as toxic (Table 8) are often referred to as heavy metals and in some cases trace elements. Therefore, wastewaters containing significant concentrations of these toxic elements or compounds are generally not suitable for land application to most soils. At varying levels these toxic substances are detrimental to both plant and microbial growth.

The two principal areas of concern related to application of these toxic elements are as follows:

- 1) the possibility of causing toxicity to plants,
- 2) the potential of degrading groundwater.

Table 8 lists a number of toxic substances of concern in land application systems and their maximum allowable concentrations in wastewaters to be applied to land. If the concentrations of any of these are greater than these defined limits, monitoring of the raw wastewater and

TABLE 8 TOXIC ELEMENTS AND RECOMMENDED MAXIMUM LEVELS
FOR CONTINUOUS USE IRRIGATION WATER [11]

Element	Maximum Level For Continuous Use Irrigation Water, All Soils (mg/L)
Aluminum	5.0
Arsenic	0.10
Beryllium	0.10
Boron	0.75
Cadmium	0.010
Chromium	0.10
Cobalt	0.05
Copper	0.20
Fluoride	1.0
Iron	5.0
Lead	5.0
Lithium	2.50
Manganese	0.20
Mercury	No data
Molybdenum	0.01
Nickel	0.20
Selenium	0.02
Silver	No data
Zinc	2.0

Note: Allowable concentrations in wastewater before harmful effects may be exerted on the soil, crops and/or groundwater.

of the soil regime including groundwater may be necessary.

It is interesting to note that many of these toxic elements occur naturally, usually in very low concentrations, and that some are essential to microbial and plant life. For example, boron is an essential plant micronutrient but is toxic to many plants at concentrations of 1 to 2 mg/L. The tolerance of plants to toxic substances is important when considering cover crops for land application systems and is discussed further in Section 5.2 of this manual.

While toxic elements are potentially dangerous, it is generally agreed that the following elements are the most likely to cause problems:

- boron,
- cadmium,
- zinc,
- copper,
- nickel.

In the case of food processing wastewaters these toxic elements are not normally a problem.

3.2.11 Bacteria and viruses

Food processing wastewaters from animal processing plants (meat, fish and poultry) may contain pathogenic bacteria and viruses. Salmonella bacteria are of particular concern. Any food processing plants which combine process wastewater with domestic sewage from the plant may also discharge these potentially harmful pathogens.

In most land application systems, the soil mantle is efficient in the removal of bacteria. Viral organisms are also thought to be removed efficiently by the soil mantle through the processes of filtration and adsorption; however, some concern has been expressed since recent studies have confirmed viral infection resulting from land application of wastewaters. Further discussion of this topic and of its potential impact to public health is contained in Section 8 of this manual.

To assess the ability of a land application system to remove pathogens, concentrations in the wastewater and in the soil should be monitored regularly. If they are not destroyed through soil mechanisms (Section 2.1.1) it may be necessary to disinfect the wastewater prior to its disposal to land.

When a spray application system is to be utilized, consideration should be given to the transport of pathogens in resultant aerosols. Buffer zones around the site or disinfection of the wastewater may be needed. Restricted access to the application area may also be required.

3.2.12 Sodium adsorption ratio (SAR)

The relationship between the principal cations in wastewater, especially calcium, magnesium and sodium, is very important. When the ratio of sodium to calcium plus magnesium becomes too high, the sodium tends to replace the calcium and magnesium ions on clay particles and has the effect of dispersing the soil particles and consequently reducing the soil permeability. These effects are discussed in Section 2.1.2.

The sodium adsorption ratio (SAR) can be calculated from the following equation:

$$SAR = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{0.5}} \text{ ----- (1)}$$

where Na, Ca and Mg are the concentrations of the respective ions in milliequivalents per litre of water. Experience has shown that problems of clay dispersion can be related to the value of the SAR as follows:

- 1) no problem expected: SAR less than 6.0,
- 2) increasing problems expected: SAR between 6.0 and 9.0,
- 3) severe problems expected: SAR greater than 9.0.

3.2.13 Oil and grease

Wastewaters from meat processing plants contain relatively high concentrations of oil and grease from cutting, deboning, and rendering operations.

Excessive concentrations of oil and grease may interfere with the operations of a land application by causing severe clogging of the soil pores. Where this may occur, catch basins or flotation tanks may be required to remove grease.

3.3 Pretreatment Requirements

Wastewater pretreatment is required in most cases to eliminate frequent operating difficulties, and in some cases, to avoid adverse effects on the land environment. Some of the pretreatment requirements which may be necessary have been previously discussed earlier in this section. Additional detail is given in Section 6.

The more common pretreatment facilities that may be needed and that are most commonly used, are discussed below.

Screening. Coarse solids contained in the wastewater can cause serious problems with the distribution of the effluent, especially during spray irrigation. In addition, these solids can coat the land surface with an impermeable layer. Screening is a relatively simple and inexpensive pretreatment method which can be utilized to separate or remove the coarser solids from the wastewater.

Sedimentation. Sedimentation may be required to remove silt and other suspended solids which may contribute to the clogging or erosion of transmission pipes and distribution nozzles. These solids are normally associated with washing and fluming operations in fruit and vegetable processing plants.

Oil and grease removal tanks may be required for meat and poultry processing wastewaters which contain excessive grease concentrations.

Cooling. Cooling may be required for wastewaters with temperatures greater than 70°C (150°F). If the temperature is much greater than 70°C, special facilities for cooling (towers, ponds, etc.) should be incorporated into the land application system. If the temperature is less than 70°C sufficient cooling would normally be obtained from the application to the land. Cooling by sprinkling can be enhanced by the use of nozzles that produce small spray droplets or that have large spray diameters.

pH adjustment. The pH of applied wastewater should be in the range of 6 to 9. Sustained flows of wastewater with pH values above or below this range should be neutralized prior to land application. In those cases where the wastewater pH fluctuates, a flow equalization basin may be required. It may be necessary to control pH, depending on the average value after equalization.

Lagooning. Lagooning or holding of wastewaters prior to discharge to the land may be used for the following reasons:

1. To remove silt and other suspended solids.
2. To equalize the wastewater loading, both hydraulically and organically, and thus allow for more consistent operation of the land system and prevention of shock loading to the soil/plant regime.
3. To lower the organic (BOD_5) content of the wastewater, should the organic loading rate associated with an untreated wastewater be greater than that capable of being handled by the system.

Aeration. Aeration of the wastewater prior to land application may be required to control malodours. These malodours are caused by the onset of anaerobic conditions and may be especially prevalent in wastewater which must be transmitted over long distances before application or which is stored in holding ponds.

Aeration requirements may range from one-half hour or less for recently produced wastewater being held in a small holding tank, to several days or even weeks for effluent stored over the winter in large holding ponds. In order to control odours aeration must be sufficient to provide a slight residual dissolved oxygen concentration in the wastewater.

Nutrient addition. Nutrient addition in the form of nitrogen and/or phosphates may be necessary for nutrient deficient wastes, either to the wastewater or to the land in terms of fertilizer application.

3.4 Wastewater Characteristics of Various Food Processing Industries

The range in wastewater characteristics exhibited by most food processing plants within each industry varies greatly from one plant to

another, and within the plant itself depending on the commodity being processed and the technology being used. This variability is illustrated by the range of characteristics exhibited by poultry processing plants and given in Table 9. Values of BOD_5 range from 3.26 kg/tonne to 19.86 kg/tonne. Table 10 summarizes the range of results obtained from a specific meat packing plant [13]; BOD_5 values range from 200 to 115,000 mg/L and phosphorus from 3 to 35 mg/L.

The data provided in these two tables emphasize the need for comprehensive wastewater analyses to determine the range in characteristics and the average value to be expected. The data in Table 10 illustrate the large variation in wastewater characteristics which may be possible even for a specific plant. However, in this particular situation, an extensive testing program indicated that the average wastewater characteristics to be expected were at the lower end of the range, and land application was possible. A land application system was installed at this plant and has been operating satisfactorily.

Meat and poultry processing plants (including rendering plants)

Meat and poultry packing plant wastewater contains most of the pollutants found in domestic wastewaters, except that concentrations are usually 3 to 10 times higher. Wastewater from these plants can be treated effectively by a properly operated soil system. In the design of a land application system, special consideration should be given to the following potential problems:

- 1) possible presence of pathogenic bacteria in the wastewater,
- 2) severe groundwater pollution from high concentrations of nitrates,
- 3) high concentrations of grease could potentially cause problems associated with soil clogging,
- 4) unfavourable sodium adsorption ratios, due to high use of common salt in most meat packing plants, can cause severe problems with soil particle dispersion and reduced soil permeability. A maximum salt content of 0.15 percent has been suggested in wastewater to be applied to the land.

Figure 8 illustrates the relatively high strength of meat packing plant effluent which is being applied to the land.

TABLE 9 WASTEWATER CHARACTERISTICS OF POULTRY PROCESSING WASTEWATERS [51]

Parameter	Units	Range
Wastewater Flow	L/bird	15.9 - 87.0
BOD ₅	kg/tonne LWK*	3.26 - 19.86
SS	kg/tonne LWK	0.13 - 22.09
COD	kg/tonne LWK	2.04 - 56.81
Grease	kg/tonne LWK	0.12 - 14.03
TDS	kg/tonne LWK	3.52 - 45.8
TKN	kg/tonne LWK	0.15 - 12.16
NH ₃	kg/tonne LWK	0.005 - 0.73
NO ₃	kg/tonne LWK	0.0 - 0.14
NO ₂	kg/tonne LWK	0.0 - 0.037
TP	kg/tonne LWK	0.054 - 2.46

* LWK denotes liveweight killed.
tonne = metric tonne (1000 kg).

TABLE 10 WASTEWATER CHARACTERISTICS EXHIBITED BY A SPECIFIC MEAT PACKING PLANT [13]

Parameter	Range (mg/L)
BOD ₅	200 - 115,000
COD	307 - 160,000
Grease	285 - 8,160
P	3 - 35
TKN	27 - 1,200
Total Solids	950 - 13,980



FIGURE 8. EFFLUENT FROM A MEAT PACKING PLANT BEING APPLIED TO CROPLAND.

Fish processing plants

The special considerations concerning the application of fish processing wastewater to the land are similar to those given for meat and poultry plants. In the case of salt water fish processing, potentially high salt content in the wastewater may cause unfavourably high SAR values.

Fruit and vegetable processing plants

The wastewater characteristics from a fruit and/or vegetable processing plant are highly variable and are dependent on the processing operation and the raw product(s) being processed. A number of points concerning the application of this industry wastewater are given below:

- 1) Most fruit and vegetable processing wastewaters are nutrient deficient. Some major commodity exceptions are corn, peas, and in some cases potato wastewaters. Since these wastewaters are nutrient deficient, nutrient loading is not normally a limiting factor. However, the potential for nitrate contamination is present.

- 2) pH control is important. Low values are often associated with processing acidic fruits while higher values are often due to lye peeling operations.
- 3) High sodium content in wastewater, and thus higher SAR ratios, can result because of the use of caustic peeling processes. This can especially be prevalent in potato processing plants. Gypsum (CaSO_4) lime, calcium chloride, and iron, sulphur or aluminum sulphate can sometimes be applied to lower the SAR, depending on specific conditions.
- 4) Wastewater screening is definitely required in most fruit and vegetable processing plants because of the production of coarse solids such as pits, skins, cores, rejects, etc.

Dairy processing plants

In general, dairy wastes contain high concentrations of organics and have a highly variable pH. Land application considerations involving dairy wastewaters are as follows:

- 1) possible presence of pathogenic bacteria in the wastewater,
- 2) severe groundwater pollution resulting from high concentration of nitrogen that may be present in the wastewater,
- 3) the pH of dairy wastewater varies widely and is largely dependent on the detergent being used to wash processing equipment. pH adjustment to maintain values between 6 and 9.5 would most probably be required.

Beverage industries

Very little information is available concerning potential problems in the land application of wastewater from this industry. A particular reason for this lack of information is that these plants are normally located within urban centres and thus wastewater disposal is via a municipal treatment system.

Available information on the characteristics of winery stillage would indicate that high organic, nitrogen and phosphorus leaching can be anticipated. In addition, the wastewater is normally acidic and would require neutralization.

4 CLIMATIC CHARACTERISTICS

4.1 Introduction

Climatological factors play an important role in the design of land application systems. The magnitude of climatic effects depends on the category and method of application, the type of equipment used and the volume of wastewater applied to the land.

The purpose of this section is to discuss the effects of precipitation, temperature and wind on the design and operation of land application systems. The variables which should be taken into account are summarized in Table 11.

4.2 Definition and Functional Role of Each Design Variable

4.2.1 Precipitation

Precipitation in the form of rainfall, snow and hail will affect a number of design components including the following:

- 1) hydraulic loading rates
- 2) storage requirements, and
- 3) drainage system requirements.

The following variables are important in the design and operation of a land application system:

- 1) total annual precipitation,
- 2) maximum and minimum annual precipitation,
- 3) monthly distribution of precipitation,
- 4) storm intensities,
- 5) snowfall.

These variables are discussed in detail below.

Total annual precipitation. This is an important design parameter for predicting water budgets. There must be sufficient land area for wastewater application to treat and remove the net addition of water. This net addition of water is equal to the difference between additions and removals:

TABLE 11 CLIMATIC CHARACTERISTICS

Characteristics	Variable
Precipitation	Annual Total Annual Maximum and Minimum Monthly Distribution Storm Intensities Snowfall - Annual Total - Expected Depth - Duration of Snow Cover
Temperature	Monthly Distribution Seasonal Distribution - Potential Evapotranspiration Growing Season Length Frost Duration Period
Wind	Prevailing Direction Speed

- additions - rainfall, snow, hail,
 - wastewater.
- removals - plant uptake,
 - evaporation,
 - soil percolation.

Maximum and minimum annual precipitation. These parameters may be significant in specific locations. For example, special design provisions for drainage may be required in those areas where the difference between the average annual precipitation and the maximum annual precipitation is large.

Minimum average annual precipitation may be important where design liquid loadings are low and the applied wastewater alone would not be sufficient for optimum vegetative growth. A plan for reduced crop acreage or for supplemental irrigation water should be included in such a situation.

Monthly distribution of rainfall. Values are useful for predicting seasonal variations in application rates and storage requirements during the non-growing season, especially winter.

Storm intensities. Values are required for the design of drainage and runoff collection systems. Increased runoff due to storms is an important consideration in the design of irrigation systems but is not as important for overland flow and infiltration percolation systems. Infiltration percolation systems are designed to maximize subsoil drainage; in contrast, overland flow systems are designed to maximize the handling of water through runoff collection and therefore can accommodate storms better than spray irrigation systems.

Snowfall. The following data are important:

- 1) Total amount of snowfall
 - for the design of additional storage volume.
- 2) Expected depth
 - periods of snow cover will necessitate effluent storage for later application.

3) Duration of snow cover

- for the design of storage volume requirements.

In some areas of the country, infiltration percolation systems may be operated successfully during snow cover. The success of operation of such systems is, however, dependent on depth of snow cover.

4.2.2 Temperature

The ambient temperature affects wastewater loading rates and the period of wastewater application. Microbial processes in the soil result in the decomposition of organic matter and transformation of nutrients; these processes are dependent on temperature. Chemical and physical processes, occurring in the soil and important for wastewater treatment, are also temperature dependent. Finally, cover crop growth patterns are controlled as much by temperature as by moisture availability.

The following temperature data are important in land application system design:

- 1) monthly or seasonal averages,
- 2) length of the growing season,
- 3) frost duration period.

Monthly or seasonal averages. These data may be used as a basis for the selection of cover crops which can be grown successfully. The length of growing season and tolerance to high and low temperatures varies considerably depending on the species of plant. Local agricultural crop experts can usually make recommendations where this is required.

Air temperature distribution data are very important in the design of irrigation application systems. These data are used to predict quantities of water removed by plants and by evaporation.

Water is removed from the soil through the plant roots and is lost to the atmosphere from the leaves by a process known as transpiration. Water is also lost to the atmosphere by direct evaporation from the soil. This combined water loss to the atmosphere is defined as evapotranspiration.

The rate of evapotranspiration is a function of several variables including precipitation, wind, availability of soil moisture and vegetation characteristics. However, temperature is the single most important variable which determines evapotranspiration rates for the design of irrigation systems.

Length of the growing season. The length of the growing season is defined as that period of time which begins when the five-day mean air temperature reaches and stays above 5.5°C (42°F) and which ends when the five-day mean air temperature falls below 5.5°C (42°F).

It is important to predict planting dates for crops such as grain and row crops and to predict the active growth period for perennial crops such as grasses and forest vegetation. In addition, the length of the growing season is important in the sizing of storage facilities, especially for systems designed for irrigation and overland flow, and for those infiltration percolation systems with vegetation cover.

Frost duration period. This period may include that when the ground is frozen or that between the first and last frosts of the season. Wastewater generated during this period of time may be stored either in a storage reservoir or as ice banks. The length of this period will determine the size of storage facilities; for example, see the description of Plant J in Section 9. Caution must be exercised during application of wastewater under freezing conditions. Figures 9 and 10 illustrate typical freezing problems which may occur with spray irrigation systems.

4.2.3 Wind

The prevailing wind directions and speed are important where spray irrigation is used and aerosol drift to nearby communities may be a problem. These wind data are useful in predicting buffer zone requirements around the wastewater treatment facility. In addition, prevailing wind direction should be considered where odour transmission is a potential problem, particularly from stored effluents.



FIGURE 9. FREEZING OF WASTEWATER EFFLUENT ON A SPRAY NOZZLE.



FIGURE 10. COLLAPSED SPRAY IRRIGATION SPRINKLER BOOM AS THE RESULT OF FREEZING.

4.3 Determination of Variables

Many of the relevant climatic data are available from the Atmospheric Environment Service of Fisheries and Environment Canada. Some data have been summarized pictorially in atlases while others have been tabulated. Appendix II contains abstracts of many of these data which are available.

Because the combined effects of temperature and precipitation are important in the design and operation of land application systems, empirical equations have been developed to describe this effect. The allowable hydraulic loading by irrigation methods is equal to the difference between the evapotranspirative loss and the amount of water added to the system by precipitation. This water deficit or irrigation requirement has been determined by the budgeting procedure described by Baier and Russelo [14]. The relationships which have been developed for the scheduling of crop irrigation systems are equally applicable to irrigation methods for wastewater application.

In the budgeting procedure, the water deficit is determined by evaluating the following expression:

$$AW_e = AW_b + (P - PE \cdot CU) \quad (1)$$

where: AW_e = water readily available to crops, in the soil at the end of the time period considered.

Water readily available to crops is water in the soil capable of being transpired at the potential rate; it is approximately 50% of the total available water capacity.

AW_b = water readily available to crops in the soil at the beginning of the time period considered.

P = total precipitation occurring during the period considered.

PE = potential evapotranspiration for the period (determined empirically); potential evapotranspiration is defined as the maximum quantity of water capable of being lost as water vapour, in a given climate, by a continuous stretch of vegetation which is adequately supplied with water.

CU = consumptive use factor (ratio of the actual consumptive use of water by the crop to PE).

Two situations should be considered:

1. $(P - PE \cdot CU) < 0$

More water is used by the cover crop than is added to the soil by precipitation and the deficit is supplied by the readily available water in the soil.

Once the readily available water has been exhausted the allowable wastewater hydraulic loading rate is the amount by which AW_e is less than zero.

2. $(P - PE \cdot CU) > 0$

Precipitation exceeds consumption and AW_e increases up to the maximum associated with that particular soil. Water in excess of this amount is considered to be lost to runoff and/or to deep percolation. Most of the applied wastewater is collected as runoff in an overland flow system; most is removed by deep percolation in an infiltration-percolation system. Thus this water deficit parameter has limited usage in the design of these systems. It is, however, very important in the design of irrigation systems where most of the water is removed by consumptive use.

The soil water deficit is also dependent on the time over which budgeting takes place, the soil water content at the beginning of the budgeting period, the water holding capacity of the soil, and the consumptive use factor.

Soil moisture deficit maps have been developed for Canada [15]. It is recommended that these maps be used in the design of wastewater irrigation systems to predict annual hydraulic loading rates. Several assumptions were made in their development:

- 1) The period from May to September was selected as the budgeting interval. This period is generally considered to be the growing season for crops on a Canada-wide basis.
- 2) The water content of the soil at the beginning of the growing season is assumed to be at capacity. This is a reasonable assumption for areas having wet spring and wet fall; in dry regions, the

water deficit during the summer is so large that the error associated with this assumption can be neglected.

- 3) The consumption use factor is unity for all cases (based on the consumptive use factor for alfalfa and grass in Canada).

Although the active growing season for alfalfa and grass usually extends for the full period of May to September, the active growth period for grains and root crops is approximately three months. The consumptive use factor for these crops is therefore 0.6 and the water deficit for these crops is 60% of the value taken from the maps.

These soil moisture deficit maps may be obtained from:

Agrometeorology Research and Service Station
Chemistry and Biology Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario
K1A 0C6

When ordering these maps they should be referred to by the following titles:

- 1) Map 1 - Seasonal Water Deficits; 50% Probability, May - September 1931-60; 25 mm Storage; Consumption Use Factor, 1.00.
- 2) Map 2 - Seasonal Water Deficits; 50% Probability; May - September 1931-60; 100 mm Storage; Consumptive Use Factor, 1.00.

In order to determine which of the two maps should be used to predict seasonal water deficit, the effective rooting depth (Section 2.2.3) and the available water capacity of the soil (Table 2) must be known.

Once the effective rooting depth has been determined the available water capacity for that soil depth should be determined from Table 2. For many soils the texture of the subsoil layers is not the same as that of the surface. In estimating the available water capacity for the effective rooting depth, the textures and depth of each texture

should be determined. The total available water capacity is the sum of each individual layer.

The empirical data used to develop the soil moisture deficit maps have been developed by using the readily available moisture capacity which is arbitrarily defined as one-half of available water capacity. It reflects the fact that water is not equally available to plants over the available water range. It is the average amount of available water capacity which can be removed before irrigation is required.

In order to illustrate the use of the maps, assume that wastewater is being applied to a field of grass. The following soil horizon information has been determined.

- 1) 0 to 12 cm - medium textured very fine sandy loam,
- 2) 12 to 30 cm - moderately coarse textured sandy loam,
- 3) 30 to 45 cm - very coarse textured sand.

From Section 2.2.3 we determine that the effective rooting depth for grass is 45 cm. The soil water storage capacity is then determined in the following way:

Soil Depth (cm)	Available Water Capacity (cm/m) (from Table 2)	Readily Available Water Capacity* (cm/m)	Soil Water Storage Capacity (cm)**
0 - 12	13	6.5	0.78
12 - 30	10	5	0.90
30 - 45	4	2	<u>0.30</u>
Total soil moisture storage capacity =			1.98 cm (198 mm)

* 50% of Available Water Capacity.

** Readily Available Water Capacity x Soil Depth.

Since the total soil moisture storage capacity for the combination of crop and soil texture is 198 mm, the second map is used (100 mm storage).

5 PREDESIGN REQUIREMENTS

5.1 Introduction

The application of wastewater to land is a relatively low capital and operating cost method for the treatment of food processing wastes. A discussion of capital and operating costs is given in Section 7. The capability of land application systems is discussed in Section 1; however, the applicability under given conditions depends on a preliminary assessment of specific site constraints.

It was emphasized in the introduction to this manual that the treated wastewater quality requirements must be clearly defined. In addition, the objectives of the wastewater handling system (cover crop type, production, etc.) must also be set out. A preliminary assessment of the ability of the land application treatment systems to meet these objectives would then be made.

The objective of this section is to discuss the following factors which should be assessed prior to the selection and design of a specific land treatment system.

- 1) Land availability.
- 2) Suitability of available land.
- 3) Wastewater treatability.
- 4) Environmental control regulations.

5.2 Land Availability

5.2.1 Area requirements

The relative availability of land at potential sites and the probable price should be determined early in the evaluation.

Although precise land requirements will be determined later in the design process, approximate estimates are sufficient at this stage for the purpose of preliminary evaluation. The land area should be sufficient to handle present and projected wastewater flows and to provide adequate buffer zones, particularly in those locations where urban encroachment is a consideration.

Design information on a number of land application facilities presented in Section 9 may be used as a guide to obtain initial estimates of land requirements.

Lengths and costs of wastewater transmission routes should be determined. In many cases, it may be possible to balance increasing costs for transmission against decreasing land values, especially if the proposed site is located in a sparsely developed outlying area.

5.2.2 Compatibility with present and future land use

Planning documents such as local wastewater management plans or regional management plans should be consulted with regard to the siting of the wastewater treatment facility. Planning commissions and zoning authorities should be contacted to determine the following for the specific sites and general area under consideration:

- 1) whether or not land application of wastewater will be permitted,
- 2) projected future population densities,
- 3) long-range planning objectives,
- 4) integration of planning objectives with the land application of wastewater.

5.2.3 Public acceptance

A public information program should be established as soon as possible especially when alternatives under consideration may be controversial. It is essential that the expression of public opinion be encouraged at an early stage so that adequate consideration and response may be given to areas of concern. Efforts should be made to ensure that all areas of concern are addressed and alleviated where possible within the constraints of the project. It is recommended that lines of communication be maintained with the public at this stage and throughout the development of the project.

5.3 Suitability of Available Land

The soil system is one of the major components of any land application system. The surface and subsurface characteristics of the soil will determine the success of a land treatment system in achieving

wastewater treatment objectives. Important soil characteristics which may determine the suitability of land application treatment for a specific site include: topography, hydrogeology, and soil type. These characteristics are now discussed to assist in the preliminary evaluation of a specific site. Reference is made to Section 2 for details on soil and plant characteristics.

5.3.1 Topography

The topography of the site and adjacent land is critical to the selection of land treatment systems. Ground slope, usually expressed as a percentage, is an important site characteristic for the choice of land treatment method and application technique.

Some approximate ranges of ground slopes suitable for specific land application systems are given in Table 12.

TABLE 12 GROUND SLOPE REQUIREMENTS

Slope (%)	Land Application Method
less than 2	Irrigation by flooding
2 to 8	Overland flow
5 to 15	Sprinkler irrigations of crops
30 (maximum)	Sprinkler irrigation of grass

Inspection of this table shows that slopes up to 15 percent and 5 percent can usually be used for sprinkler and surface crop irrigation, respectively. Slopes of up to 30 percent may be adapted to sprinkler irrigation where noncultivated crops such as grass are grown. The overland flow process normally requires slopes of two to eight percent while irrigation by flooding requires ground slopes of less than one percent.

In general, topography may be a limiting factor where low water infiltration into the soil results in runoff and soil erosion. Under these circumstances, the maximum slope figures given in Table 12 would have to be reduced. The use of topographic maps and field studies

of possible application sites will permit the identification of areas with slopes suitable for each land treatment process and method of application.

5.3.2 Hydrogeology

Hydrogeological characteristics are important for the removal of water that is not lost by evapotranspiration. The depth to bedrock should be known, especially if the bedrock is near the surface. A shallow root zone may severely restrict plant growth and groundwater movement. The natural drainage capacity, when severely hampered, may greatly increase project costs by necessitating artificial subsurface drainage.

Where data on soil depth, permeability and groundwater elevations are available, the natural drainage capacity of an area and the groundwater movement can be estimated and the need for artificial subsurface drainage determined. Where the required data are not available, a preliminary field investigation may be required in order to evaluate differences in available sites.

5.3.3 Soil type

An important predesign activity is the characterization and classification of soils in the areas available for waste application. Although crop production is not usually the primary objective in land application systems, it is necessary to establish and maintain a reasonable plant cover, especially for irrigation and overland flow methods of treatment. Therefore it is important to select soils that have the capability of producing crops.

Soil survey maps and reports are available from provincial Departments of Agriculture; this information can be supplemented with available deep drilling core analysis data to provide the necessary information. Most provinces have established Land Classification Standards for irrigation that can be used as guidelines. Since optimum crop production is not the primary objective, wastewater application need not be restricted to the most productive land. However, sites classed as non-irrigable should not be chosen unless provisions are made for soil rehabilitation.

5.4 Wastewater Characteristics

The characteristics of the food processing wastes (BOD_5 , suspended solids, metals and trace elements) are important parameters in the design of the land application system and in assessing the effects on the soil. These characteristics and their effects were discussed in detail in Section 3.

Problems encountered by high boron concentrations and high sodium adsorption ratios are perhaps the most common; however, heavy metals and trace elements can also cause problems. Table 13 summarizes the effluent quality requirements for land application systems; recommended maximum concentrations for trace elements in wastewaters were summarized in Table 8.

Concentrations outside the recommended ranges may require special wastewater pretreatment. The practicality and economics of these requirements need to be assessed prior to selection and design of a land-treatment system.

5.5 Environmental Control Regulations

The following environmental aspects may be affected by land application systems and should be considered at the predesign stage.

- soil and vegetation,
- groundwater,
- surface water,
- animal and insect life,
- air quality.

An environmental impact assessment may be required by the regulatory authority prior to authorizing design. An outline of the requirements for a typical assessment is given in Appendix III with specific reference to food processing wastes. Environmental constraints which could arise out of the development of the land application system are discussed in Section 8.

The compatibility of land application with regulatory controls should be assessed early in the planning phase and specific regulations which must be met should be determined prior to design.

TABLE 13 EFFLUENT QUALITY GUIDELINES [16]

Problem and related Constituent	Guideline Values		
	No Problem	Increasing Problems	Severe
Salinity ^a EC of irrigation water, mmho/cm	less than 0.75	0.75 to 0.30	greater than 3.0
Permeability EC of irrigation water, mmho/cm	greater than 0.5	less than 0.5	less than 0.2
SAR (Sodium adsorption ratio)	less than 0.6	6.0 to 9.0	greater than 9.0
Specific ion toxicity ^b From root adsorption			
Sodium (evaluate by SAR)	less than 3.0	3.0 to 9.0	greater than 9.0
Chloride, mg/L	less than 4.0	4.0 to 10	greater than 10
Chloride, mg/L	less than 142.0	142 to 355	greater than 355
Boron, mg/L	less than 0.5	0.5 to 2.0	2.0 to 10.0
From foliar adsorption ^c (sprinklers)			
Sodium mg/L	less than 3.0	greater than 3.0	-
Sodium, mg/L	less than 69.0	greater than 69.0	-
Chloride, mg/L	less than 3.0	greater than 3.0	-
Chloride, mg/L	less than 106	greater than 106	-

- a. Assume water for crop plus needed water for leaching requirements will be applied. Crops vary in tolerance to salinity.
- b. Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive.
- c. Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride adsorption under low-humidity, high-evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads)

Note: Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

The Provinces of Alberta and British Columbia have formulated guidelines for discharge of effluent to land. These guidelines address system design, operation and monitoring. Although these are the only provinces with formal guidelines, each province has regulatory controls which apply to land application systems.

Provincial legislative controls on surface and subsurface disposal of food processing plant effluents to land should be determined at an early stage since licensing or approval of these facilities will be required prior to installation.

5.6 Laboratory and Pilot Plant Experiments

Laboratory and/or pilot plant experiments can be useful in investigating some of the technical aspects of the application of wastewater to land. Although considerable information can be obtained from these studies, caution is advised since the experimental conditions may be somewhat artificial. Greenhouse germination tests or growth chamber tests and on-site pilot scale studies can all be used as part of the predesign activity to assess the practicality of land-treatment for a specific site.

5.6.1 Germination tests

Germination tests may be useful to detect potentially acute toxicity resulting from the application of wastewater. The test is a comparison of germination of seeds in soil moistened with wastewater to that in soil moistened with tap water. Since the test is simple and requires few facilities, it can be used to detect the presence of compounds toxic to plants in the wastewater.

5.6.2 Greenhouse or growth chamber experiments

Greenhouse experiments are used to assess plant responses to the application of wastewater. These experiments may be carried out by comparing plant growth from wastewater application with that from tap water application. The plant tissue and soil can be subjected to chemical and physical analyses after harvesting.

These experiments require facilities for plant growth and analysis, and several months of laboratory or greenhouse experimental time.

5.6.3 Pilot studies

On-site pilot studies can provide valuable design data (waste-water application rates and soil capacities), particularly where the topography and soil type do not clearly favour one category of application over another.

Pilot studies should be conducted on representative plots, approximately 0.5 hectare in area. Flat plots may be defined by plowing a furrow around the perimeter and mounding the soil around the edges. Sloping plots suitable for overland flow systems will require a cleared ditch with a flow-measuring device (Parshall flume or V-notch weir) at the base of the slope. A network of wellpoint piezometers should be installed in and around flat areas and those sloping areas with high permeability to monitor changes in water table and groundwater quality.

5.7 Conclusions

The choice of land application as the most feasible treatment method of food processing wastewater is primarily dependent on the availability of sufficient suitable land area at relatively low cost.

Finally, public and government acceptance of the facility will be determined by the ability of the land application system to handle the wastewater in an environmentally sound manner.

6 PROCESS DESIGN

6.1 Introduction

The objective of this section of the manual is to assess alternative land treatment methods presently available and to develop design procedures for each of the main categories of land application treatment systems according to the design criteria discussed in earlier sections. In addition, a sample problem will be discussed in Appendix IV in order to illustrate the design process.

6.2 Land Application Systems

Land application systems can be classified into two main groups:

- 1) surface applications,
- 2) subsurface applications.

These groups can be further subdivided into alternative application methods.

1) Surface Applications (Figure 11)

- a) Irrigation
- b) Overland Flow
- c) Infiltration Percolation

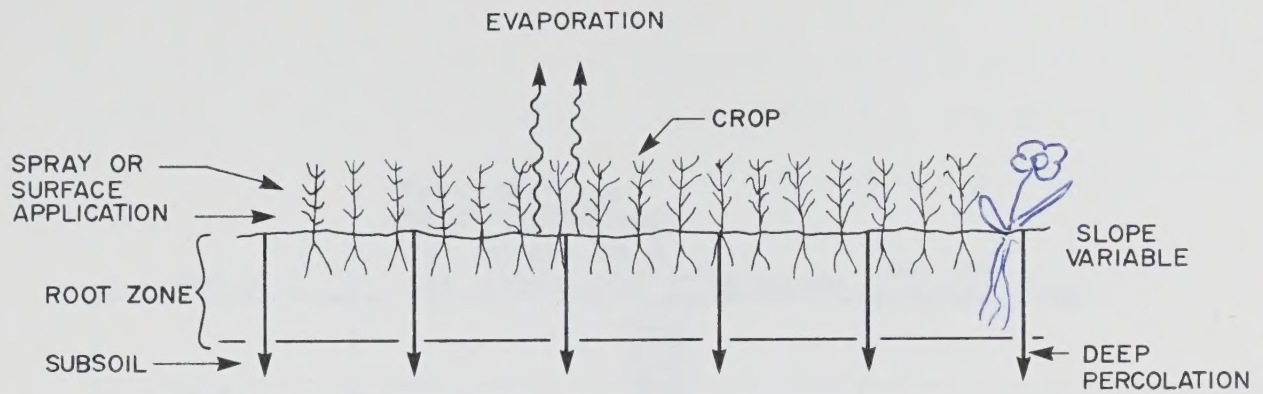
2) Subsurface Applications

- a) Subsurface leaching (Figure 12)
- b) Deep well injection (Figure 13)

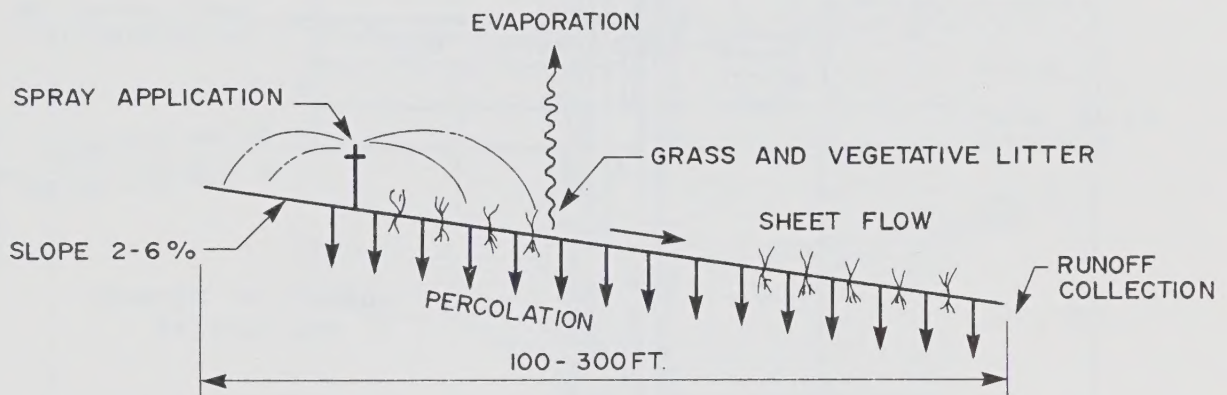
6.2.1 Surface applications

a) Irrigation

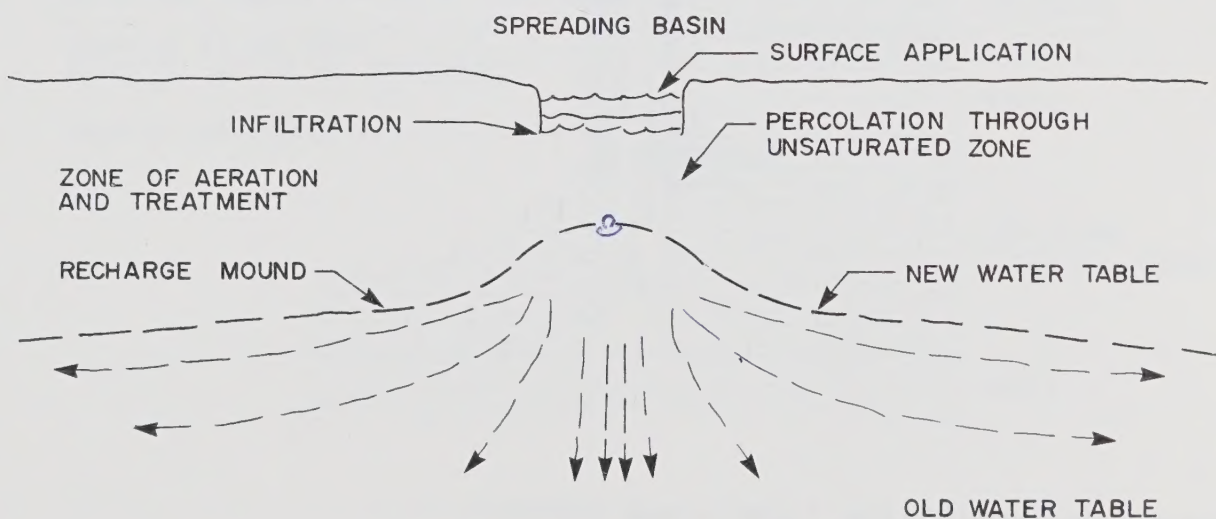
Irrigation is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. The wastewater is "lost" to plant uptake, to air by evapotranspiration, and to groundwater by percolation. Treatment of the wastewater generally occurs after passage through the first 60-120 cm (2-4 feet) of soil.



IRRIGATION

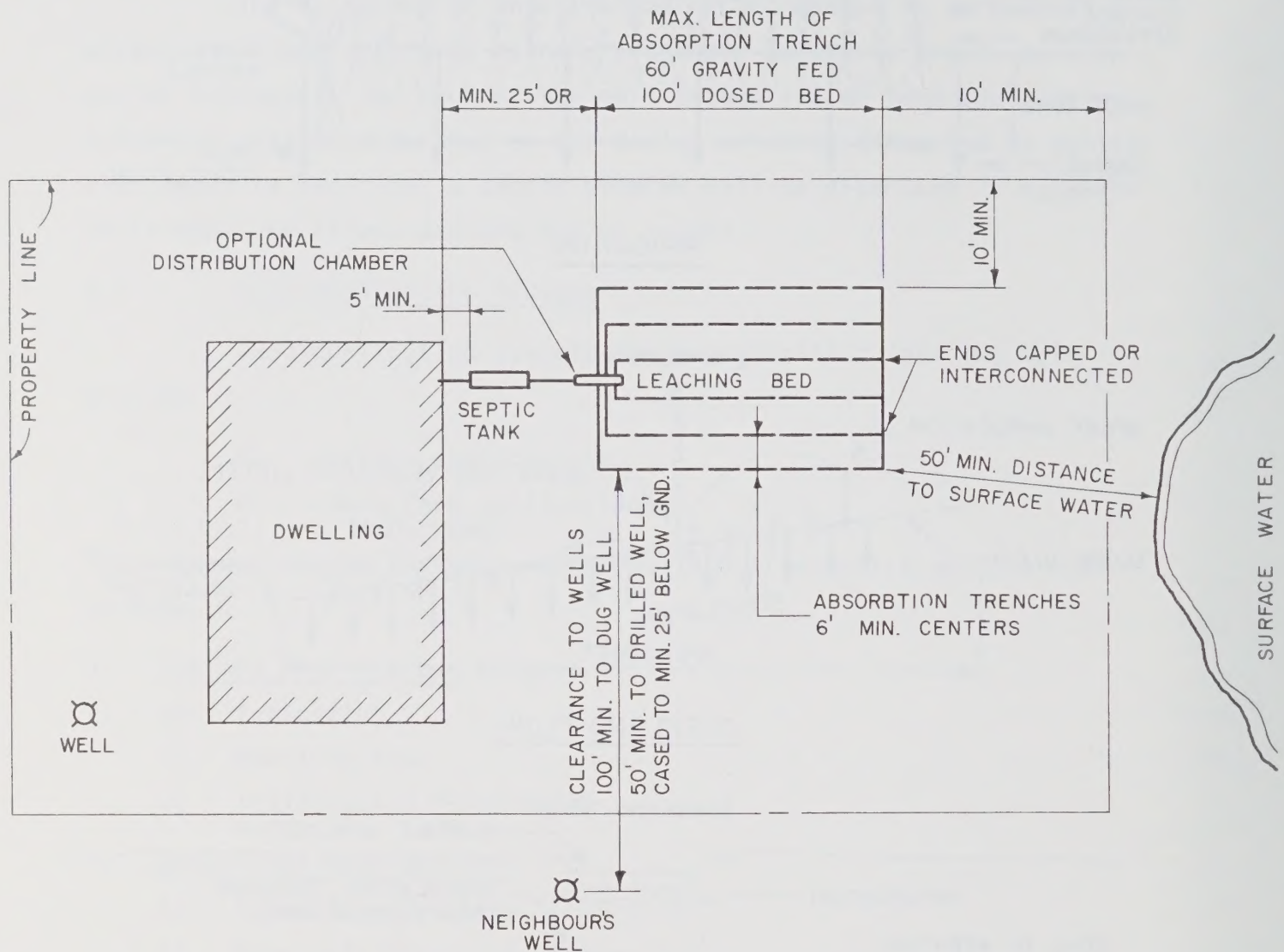


OVERLAND FLOW



INFILTRATION PERCOLATION

FIGURE 11. SURFACE LAND APPLICATION APPROACHES.



NOTE:

THIS DRAWING ABSTRACTED FROM "SEPTIC TANK SYSTEMS",
ONTARIO MINISTRY OF THE ENVIRONMENT, INFORMATION SERVICES BRANCH.

FIGURE 12. TYPICAL ARRANGEMENT OF A SEPTIC TANK SYSTEM.

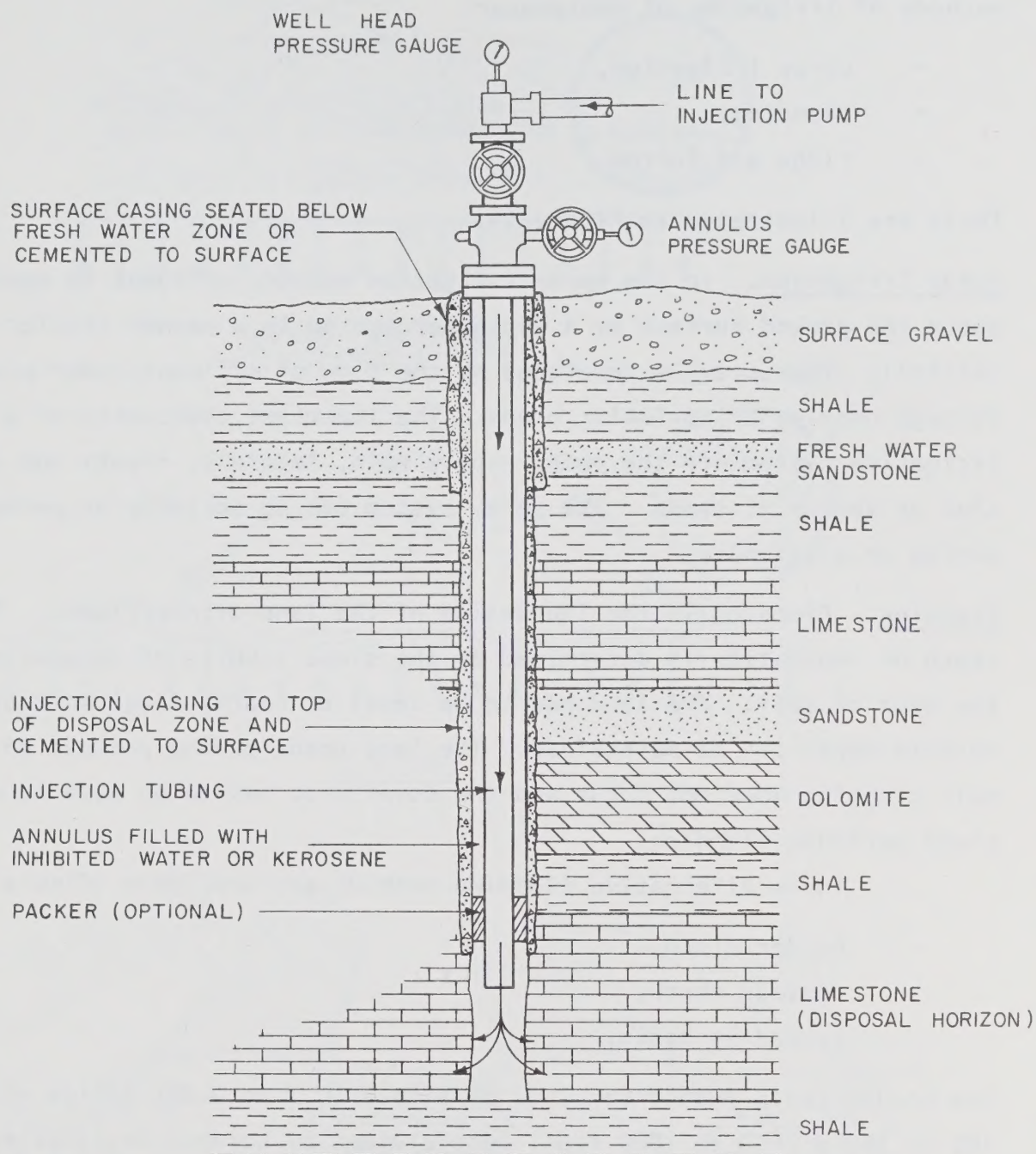


FIGURE 13. TYPICAL DISPOSAL WELL CONSTRUCTION.

The method of application depends on the soil, the type of crop, the climate, and the topography. There are three established methods of irrigation of wastewater:

- spray irrigation,
- flooding,
- ridge and furrow.

These are illustrated in Figure 14.

Spray irrigation. In the spray irrigation method, effluent is applied above the ground surface by a sprinkler system in a manner similar to rainfall. The spray is developed by the flow of effluent under pressure through nozzles or sprinkler heads. The important components of a spray irrigation system are the pump, supply main, laterals, risers and nozzles or sprinkler heads. The spray system can be portable or permanent, moving or stationary.

Flooding. Flooding is the inundation of the land with effluent. The depth of inundation is determined by the slope, choice of vegetation and the type of soil. The land has to be level or nearly level so that a uniform depth can be maintained. The land needs drying periods so that soil clogging does not occur and the cover crop has to be able to withstand periodic flooding.

Three alternative flooding methods are available (Figure 15):

- border strip,
- contour check,
- spreading basin.

The border strip method consists of sloped (0.2 to 0.3%) strips of land 180 to 300 m (600 to 1000 feet) long divided by borders or dikes every 6 to 18 m (20 to 60 feet).

Contour check is the creation of dikes along the contour of a slope. Dikes which are used to contain the effluent so it does not run down the slope are placed at contour intervals of 0.06 to 0.1 m (0.2 to 0.3 feet).

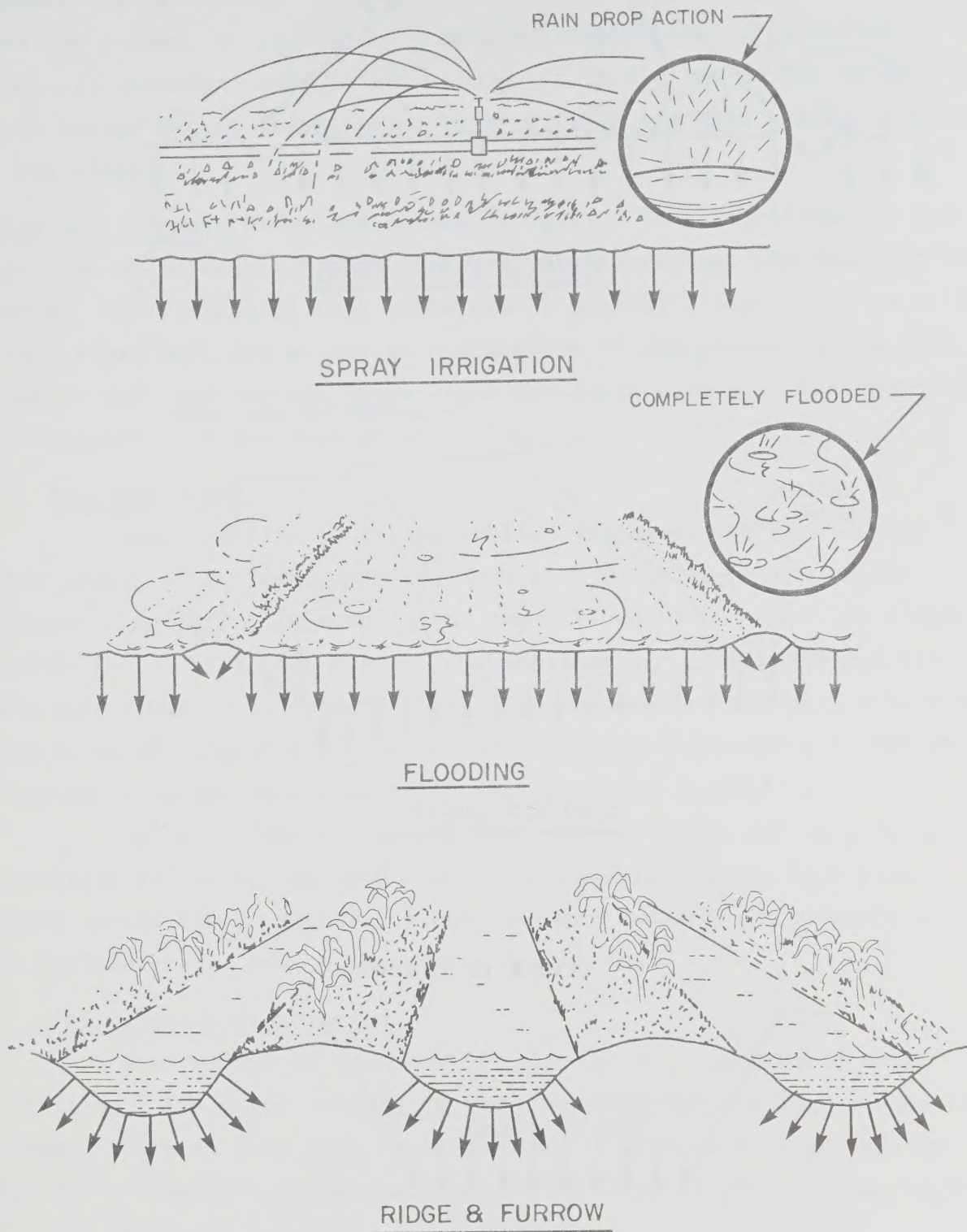


FIGURE 14. METHODS OF IRRIGATION.

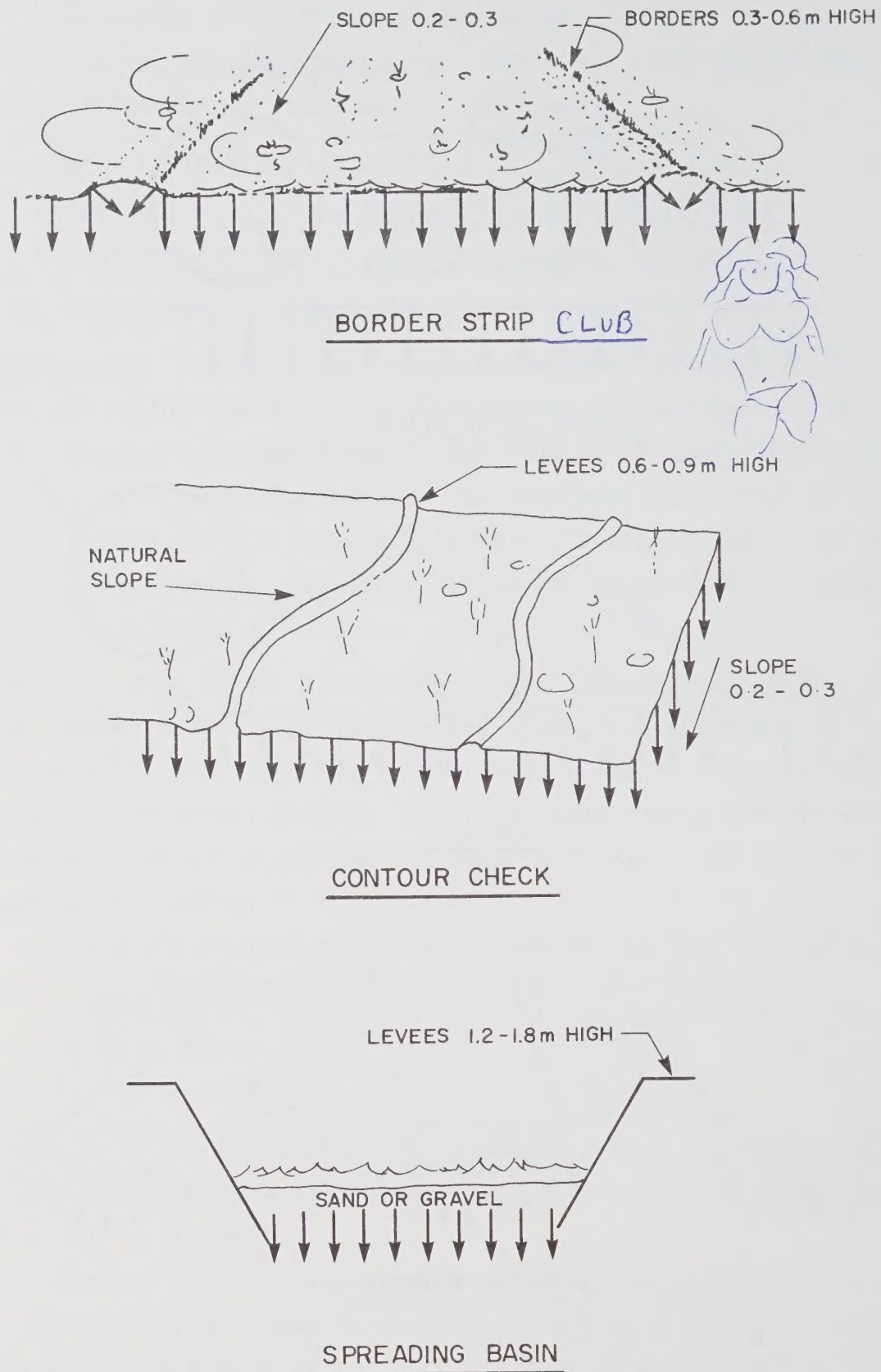


FIGURE 15. TYPES OF FLOOD IRRIGATION.

Spreading basins are shallow ponds which are periodically flooded with effluent. The basins hold the effluent until it percolates into the ground, or is used by crops, or evaporates. This method is generally used for rapid infiltration. It is similar to the border strip method except larger segments of a field are used and the ground is not sloped.

Ridge and furrow. Ridge and furrow irrigation is accomplished by gravity flow of effluent through furrows, with subsequent seepage into the ground. Utilization of this technique is generally restricted to relatively flat land, and extensive preparation of the ground is required to create ridges and furrows whose width and depth vary with the quantity of wastewater and the type of soil.

b) Overland flow

Overland flow is the controlled discharge, by spraying or other means, of effluent onto the land with a large portion of the wastewater appearing as runoff. As the effluent flows down the slope a portion infiltrates into the soil, a small amount evaporates and the remainder flows to collection channels. Wastewater treatment occurs by filtration of suspended solids by surface vegetation and by oxidation of the organic matter by the bacteria living on the vegetation litter.

Soils limited in permeability such as clays and clay loams are especially suited to overland flow. The land for an overland flow system should have a moderate slope (between two and six percent) and the surface should have no mounds or depressions.

c) Infiltration percolation

This method of treatment is similar to intermittent sand filtration. The major portion of the wastewater enters the groundwater, although there is some loss to evaporation. Soils with high infiltration and permeability rates such as coarse textured sands, loamy sands or sandy loams are required.

This process has been developed for groundwater recharge and thus the distinction between treatment and disposal for this process is quite fine. Some treatment occurs during the infiltration percolation process as the wastewater passes through the aerobic layer. The primary

purpose of this method is to provide physical removal of suspended solids and bacteria.

6.2.2 Subsurface applications

a) Subsurface leaching

Subsurface leaching systems (that is, tile fields and leaching pits) are generally limited in their range of application.

b) Deep well injection

This method discharges wastewaters underground by means of deep wells, sometimes hundreds of feet deep. This may consist of injection into deep wells, mined cavities or injection into shales as a waste/grout mixture.

6.3 Selection of Alternatives

The choice of a suitable wastewater application method is dependent on site specific factors. The major criteria considered preferable for each of the surface and subsurface methods are outlined below.

6.3.1 Major criteria for irrigation application

- 1) Warm arid climates are ideal. More severe climates are acceptable if facilities are provided to handle freezing and/or wet conditions.
- 2) Slopes up to 15 percent are acceptable provided runoff or erosion is controlled.
- 3) Loamy soils are ideal but most soils from sandy loams to clay loams are suitable.
- 4) Well-drained soil is required. Where these conditions do not exist the site may be made suitable by incorporating underdrainage systems.
- 5) Soil depth of 1.5 to 2 m (5 to 6 feet) is required for plant root development and wastewater renovation.
- 6) Geologic formations which may provide direct connection to ground-water must be avoided.

- 7) A minimum depth to groundwater of 1.5 m (5 feet) is required to maintain aerobic conditions, provide wastewater treatment and prevent surface waterlogging. Where this condition does not exist naturally, groundwater pumps or artificial drainage may be used to lower the water table.
- 8) Typical land area required for a 4540 m^3 per day (1 lmgd) irrigation system is 40 to 80 ha (100 to 200 acres). Buffer zones are frequently required for spray irrigation.

6.3.2 Major criteria for overland flow application

- 1) Soils with minimal infiltration capacity such as heavy clays, clay loams or shallow soils underlain by an impermeable subsoil are suitable for this application method.
- 2) A minimum topsoil depth of at least 15 to 20 cm (6 to 8 inches) is recommended in order to establish a cover crop.
- 3) Slopes of 2 - 4% are required to allow the applied wastewater to flow slowly over the soil surface to the runoff collection system.
- 4) Warm arid climates are ideal. More severe climates are acceptable if facilities are provided to handle freezing and/or wet conditions.
- 5) If reuse of the runoff is not possible, then a waterway or drainage system must be constructed to transport the effluent from the site. This effluent must meet the federal and provincial standards for discharge into receiving waters.
- 6) A minimum depth to groundwater of 1.5 m (5 feet) is required to maintain aerobic conditions for plant growth. Where this condition does not exist naturally, groundwater pumping or under drainage may be used to lower the water table.
- 7) Land requirements typically range from 10 to 45 ha (25 to 110 acres) for a $4540 \text{ m}^3/\text{day}$ (1 lmgd) spray irrigation system; additional buffer zones may be required.

6.3.3 Major criteria for infiltration-percolation application

- 1) Well-drained soils such as sand, sandy loams and loamy sands are required. Very coarse sand and gravel are not ideal because they allow wastewater to pass too rapidly through the first few feet where the major biological and chemical wastewater treatment occurs.
- 2) A minimum depth to groundwater of 4.5 m (15 feet) is recommended. Where this condition does not exist naturally, groundwater pumping or artificial drainage may be used to lower the water table.
- 3) The site should be flat or gently sloping. Too much slope may create lateral percolation.
- 4) Land requirements typically range from 1 to 2 ha (2.5 to 5 acres) for a high-rate system to 8 to 24 ha (20 to 60 acres) for a low-rate system for a 4540 m^3 per day (1 lmgd) wastewater application rate.

6.3.4 Major criteria for subsurface leaching application

- 1) Loams or sandy loam soils are required. Clay soils are too impermeable for subsurface leaching. Coarse soils such as sand are not ideal since they allow wastewater to pass too rapidly through the subsoil and into the groundwater before biological and chemical treatment of the wastewater takes place. There should be at least three feet of this permeable unsaturated soil below the bottom of the seepage bed.
- 2) A minimum depth to groundwater of 4.5 m (15 feet) is recommended. Where this condition does not exist naturally groundwater pumping or artificial drainage may be used to lower the water table.
- 3) Geologic formations which may provide direct connection to groundwater should be avoided.
- 4) Although warm arid climates are ideal, subsurface leaching may be used successfully at freezing air temperatures as long as the soil does not become frozen.

6.3.5 Major criteria for deep-well injection

- 1) The disposal formation should have sufficient thickness and areal extent to prevent "breakthrough" of wastewater.
- 2) Injection zones must be adequately separated both horizontally and vertically from potable water zones. These distance requirements will be determined by provincial regulatory agencies.
- 3) Wastewater injection must not endanger present or future use of mineral resources such as coal, oil, gas and brine.
- 4) Wastewater injection must not affect existing or potential gas storage or freshwater storage projects.
- 5) Back pressure of fluids in the disposal formation must be low in order to minimize the change of backflow in case of pump or well failure.

6.3.6 Relationship to detailed design procedures

Following a preliminary assessment of site characteristics, feasible alternatives should be selected. The procedures discussed under Predesign Requirements in Section 5 will be useful in making those decisions. The final selection of a "best" alternative will be based on practicality, economics and regulatory requirements.

Subsections 6.4 to 6.9 discuss the procedures required to develop the detailed design of a land application system. The steps in process design for land application systems were illustrated in Figure 1. These steps will be followed in sequence in discussing the detailed design of each category of land application.

Subsections 6.4 to 6.6 discuss the design of the three application methods for irrigation of wastewater. Subsequently, subsections 6.7 to 6.9 will discuss design of overland flow, infiltration-percolation and subsurface disposal system.

The discussion of design methods is followed by an appropriate design example.

6.4 Spray Irrigation

6.4.1 Pretreatment requirements

Pretreatment requirements for food processing wastes may include one or more of the following processes:

- a) coarse screening for suspended solids removal,
- b) pH adjustment,
- c) deodorization,
- d) biological pretreatment.

a) Coarse screening

Coarse screening may be required for the removal of solids which clog spray nozzles or for the removal of grit which may accelerate the erosion of pumping and transmission equipment.

The three types of screens normally used include stationary, vibrating and rotating screens.

Stationary screens. Stationary screens usually consist of a bar screen similar to those used in a municipal treatment plant. The function of this type of screen is to remove any large foreign objects that may damage downstream unit processes.

The bars are 30 to 60 mm wide and are set at 30° to 60° to the horizontal in the influent channel; the centre to centre spacing ranges from 13 to 51 mm. The screen loading and channel width are designed to maintain a flow velocity of 0.6 m/s to prevent settling of solid particles. The bar racks are generally followed by smaller mesh screens (20 to 40 mesh, that is, centre to centre wire spacings of 0.6 to 1.3 mm). In some applications a concave shaped screen employing high velocity pressure-feeding is used to handle slurries containing fatty or fibrous suspended material.

Fine mesh screens may be constructed of wedge wires; new developments in screening consist of the use of synthetic cloth (polyester, nylon, and polyethylene). Synthetic cloth media are manufactured in sizes down to 5 to 10 micron openings and have good resistance to blinding.

Vibrating screens. Motorized screens operate continuously and discharge solids continuously. These devices are being used more frequently since fewer clogging problems are experienced and a drier and more compact product is obtained.

Screen sizes range from several meshes to the inch (2.5 to 10 mm openings) to 150 mesh wire cloth (0.2 mm centre to centre wire spacing). Vibrating screens with 20 meshes to the inch (1.3 mm centre to centre spacings) are in common use.

Screen loadings vary from 1.5 to 5.4 kg/m³ and the screened wastes usually contain 70 - 96% moisture [17].

Vibrating screens operate between 900 and 3600 rpm; the screen has a total travel between 0.8 and 12.7 mm in a circular, straight line or three dimensional path. A series of smaller screens is apparently more effective than a single larger unit.

Vibrating screens are particularly effective for the removal of tomato seeds and other similar discrete particles in fruit and vegetable wastes.

Rotating screens. In the use of a rotary screen, the wastewater enters at one end and discharges solids at the other. The liquid flows outward through the stainless steel cloth or perforated metal plate and is collected in an effluent box located below the screen. External spray nozzles continuously clean the screen, which is driven by external rollers. Screen sizes are similar to those utilized in vibrating screen systems.

The screen mesh size is an important design variable. If the mesh size is too small, the cleaning requirements become excessive and loading is severely restricted. If it is too large, then relatively large particles passing through may clog spray nozzles. Screens with 1.3 to 0.6 mm openings (10 to 20 meshes per inch) are commonly used. The particular screen chosen must be designed with sufficient area to accommodate the hydraulic loading rate.

Figure 16 illustrates the use of a rotary screen for coarse solids removal in a fruit and vegetable processing plant.



FIGURE 16. COARSE SOLIDS REMOVAL BY ROTARY SCREENING

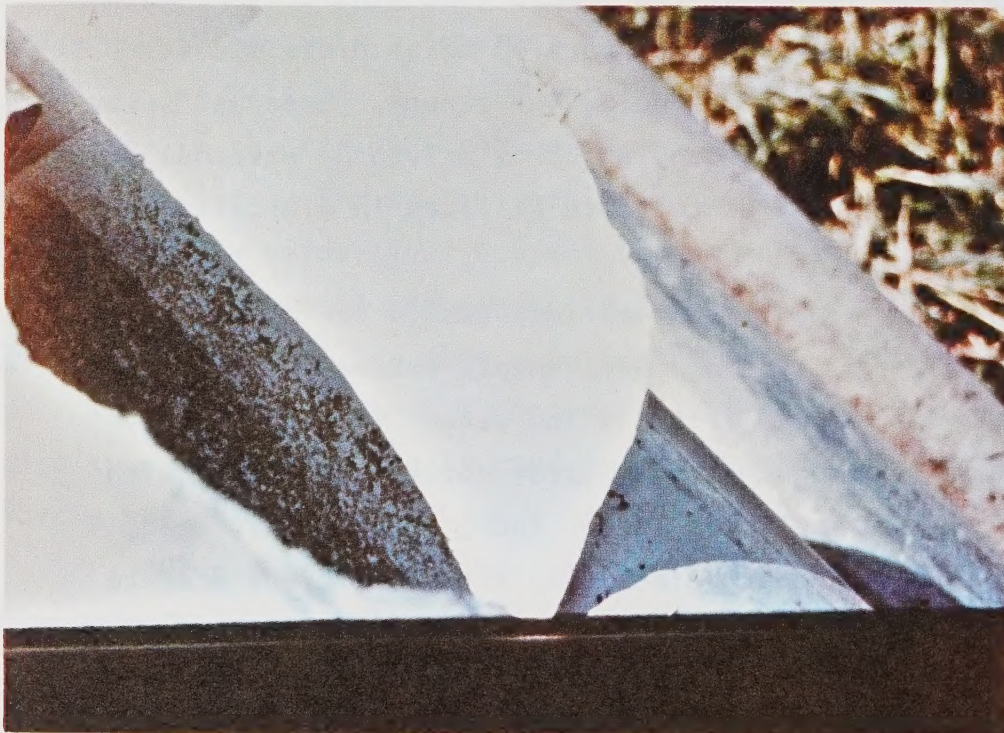


FIGURE 17. EROSION OF ALUMINUM PIPE BY WASTEWATER SUSPENDED SOLIDS

Sedimentation. Gravity sedimentation tanks may be required to remove the grit which sometimes accumulates in fluming and washing operations and which accelerates erosion of irrigation equipment. These tanks should be designed to provide a minimum of 40 to 50 minutes detention time.

Figure 17 illustrates the erosive pitting of aluminum pipe which may occur if grit is not removed prior to pumping and distribution of the wastewater.

b) pH adjustment

pH adjustment is required for those wastewaters whose pH is outside the range 6 to 9.5. Typical chemicals used include sodium hydroxide and sodium carbonate for acidic wastewaters, and sulphuric and hydrochloric acid for alkaline wastewaters.

c) Deodorization

Wastewater effluent may be deodorized prior to irrigation in those cases where odour problems exist.

d) Biological pretreatment

Biological pretreatment of wastewaters may be required where the sanitary sewage from the processing plant is being mixed with the food processing wastes. In addition, pretreatment may be required for certain meat, poultry and fish processing wastewaters to remove pathogens. These requirements will be specified by the provincial regulatory agency involved in approving the facility.

Figure 18 illustrates the use of an aerated lagoon for biological pretreatment. Aeration for control of odours prior to irrigation may be required for those wastewaters being conveyed long distances through transmission lines or being stored in holding ponds prior to land application. Both of these situations give rise to anaerobic transformations that produce malodours.

Detention times in storage basins may range from 10 to 45 minutes for small holding tanks to several days or weeks for large holding ponds. Air requirements range from 0.6 to 2.4 L/L of wastewater.



FIGURE 18. AERATED LAGOON PRETREATMENT OF FOOD PROCESSING WASTEWATER

Anaerobic and aerobic processes which have been used for treating food processing wastes include the following:

- 1) anaerobic lagoons,
- 2) facultative lagoons,
- 3) aerated lagoons,
- 4) activated sludge plants,
- 5) oxidation ditches,
- 6) trickling filters,
- 7) rotating biological contactors.

The design of these systems will not be covered in this document.

6.4.2 Cover crop selection

The choice of a suitable cover crop will depend on one or more of the following objectives:

- 1) maximum water removal,
- 2) nutrient removal,
- 3) economic return.

Specific capabilities for those crops suitable in most Canadian climates have been discussed in Section 5.2.

Sod crops such as legumes and grasses have a longer growing season than grain or row crops and therefore provide increased consumptive use of water. Forests also hold the potential for removing relatively large volumes of water (Section 5.2).

Sod crops, row crops and grain crops provide good nutrient removal. Figure 5 illustrated the nutrient removal capabilities of the various crops.

Grain crops and row crops may be used to maximize the economic benefits of a land application facility. Choice of one or more of these crops, however, may impose restrictions on the land application facility as discussed in Section 5.2.

6.4.3 Loading rate determination

a) Hydraulic loading rate. The maximum seasonal hydraulic loading rate, expressed as cm/ha/yr, should be used to determine the required land area for a land application facility. In addition, the allowable loading rate during each application or wetting period, expressed as cm/hr, should be used to:

- i) set up an irrigation schedule, and
- ii) size the application system.

The maximum seasonal rate is determined from the water deficit data discussed in Section 4.3 and from soil permeability data. The following equation was developed to describe maximum expected seasonal water removal rates:

$$R_w = P + D/10 \quad (1)$$

in which R_w = seasonal water removal rate (cm/yr)

P = soil permeability (cm/yr)

D = water deficit (mm/yr)

The following equation was developed to describe the annual soil permeability:

$$P = \frac{P_s \cdot T \cdot d}{C_i} \quad (2)$$

in which P_s = soil permeability (cm/hr); values can be taken from Table 2.

T = duration of the irrigation period during each cycle (hr/cycle); normally continuous application of waste water should not exceed a time period of 10 hours per cycle.

d = length of the irrigation season (days/yr); this will be equivalent to the length of the frost-free period.

C_i = length of the irrigation cycle (days/cycle); the significance of irrigation scheduling will be discussed in Section 6.4.5. Representative values of C_i may range from 4 days for highly permeable soils (Table 2) to 10 or 12 days for slightly permeable clay soils.

The use of maps to determine a value of D has been discussed in Section 4.3.

The following equation is then used to calculate land requirements:

$$A_w = \frac{.01 Q}{R_w} \quad (3)$$

in which A_w = total required land area (ha).

Q = total yearly wastewater production (m^3 /yr)

R_w = seasonal water removal rate (cm/yr).

In those instances where there is uncertainty regarding the ability of the soil to remove water at a rate as determined by equation (1), lysimeter studies should be carried out.

Values of P_s , T and C_i suggested for equation (2) should be used only for a preliminary assessment of the feasibility of irrigation as a wastewater treatment method (Section 6.3). Actual design should be based on results obtained from infiltration and permeability tests and pilot studies.

b) Organic loading rate. In most systems, with proper site management, the organic loading rate will not be limiting. Application should, however, be scheduled to provide adequate rest periods to allow microbial decomposition of organic matter.

The data in Table 14 summarize typical organic loading rates. It should be pointed out that rates in excess of 670 BOD_5 /ha/yr have been used in infiltration-percolation systems [19]. Before using

application rates exceeding those given in Table 14, pilot studies or laboratory column experiments should be carried out.

TABLE 14 TYPICAL BOD₅ LOADING RATES [18]

	kg/ha-hr	kg/ha-day
Fallow soil with no fresh organics	1.1 - 2.2	40
Fallow soil following addition of organic residues	2.2 - 4.5	81
Soil with growing plants	3.4 - 6.7	121
Estimated maximum BOD ₅ load to be added on well aerated soil		112

Proper irrigation scheduling is important to minimize soil clogging caused by organic overloading. In addition, periodic discing of the soil surface may be required to break up the matting produced by filtration of the suspended solids at the soil surface.

c) Nutrient loading rate. The nutrient (nitrogen and/or phosphorus) loading rate is usually not of concern with fruit and vegetable and dairy processing wastewaters. Some meat and poultry processing wastewaters may, however, contain excessive concentrations of either of these nutrients.

The nutrient loading rate to the soil must be limited such that a balance is reached between the amount applied, the amount removed by treatment and cropping and the concentration permitted to reach the groundwater. Allowable loading rates may be set by provincial regulations. The regulatory requirements should be determined prior to design.

The limiting loading rate is a function of wastewater characteristics, plant and soil characteristics and cover crop management practices. Nutrients can only be removed by crops if they are harvested.

Nitrogen removal in a spray irrigation system occurs primarily through plant uptake and harvest. Figure 4 indicated the quantity of nitrogen which can be removed in a cover crop if the crop is harvested. The following equation was developed to calculate the required land area for nitrogen removal:

$$A_n = \frac{N \cdot Q \cdot 10^{-3}}{R_n} \quad (4)$$

in which A_n = total required land area (ha)

N = nitrogen concentration in wastewater (mg/L)

Q = total yearly wastewater production (m^3 /yr)

R_n = allowable nitrogen application rate (kg/ha/yr)
(taken from Figure 4 unless otherwise specified by regulations).

In a system operated without cover crop removal, nitrogen removal may occur through the nitrification - denitrification process discussed in Section 2. Equation (4) cannot be used to predict land area requirements for such a system.

Although nitrogen removal through denitrification can be controlled, it is very difficult to predict except through pilot plant experiments. Where nitrogen loading rates may be limiting, pilot studies are required to determine optimum wetting and drying period to promote nitrification-denitrification.

Phosphorus removal occurs through plant uptake and harvest and/or by adsorption in the soil. Figure 4 illustrated the phosphorus removal rates of various crops if they are harvested. These data can be used to predict phosphorus removal, according to the following equation:

$$A_p = \frac{P \cdot Q \cdot 10^{-3}}{R_p} \quad (5)$$

in which A_p = total required land area for phosphorus removal (ha)

P = phosphorus concentration in wastewater (mg/L)

R_p = allowable phosphorus application rate (kg/ha/yr)
(taken from Figure 4 unless otherwise specified by regulations)

Q = total yearly wastewater production (m^3/yr).

If it appears that phosphorus loading rates may be limiting, laboratory column experiments or lysimeter studies should be used to estimate the phosphorus adsorption capacity of the soil.

d) Inorganic loading rate. Adverse effects of inorganic minerals in a land application system have been discussed in Section 5. The magnitude of the effects is a function of concentration in the wastewater rather than the actual soil loading rates. Table 8 summarized the allowable concentrations in the wastewater before harmful effects may be exerted on the soil, crops and/or groundwater quality.

Concentrations of inorganics are most important in determining the feasibility of spray irrigation; common problems are high boron concentrations and a high sodium adsorption ratio.

6.4.4 Selection of limiting loading rate

The maximum of the A_w , A_n and A_p values is selected as the land area required to dispose of the wastewater. These results should be confirmed through pilot studies, especially for processing plants having wastewater flows greater than $2300 m^3/day$ (500,000 gal/day) for which land costs may be significant.

6.4.5 Determination of hydraulic application rates and irrigation schedules

The application cycle (the combination of application and resting periods) should be defined in the form of an operating schedule. The length of the cycle and the ratio of wetting to drying depends on site-specific factors and may include seasonal variations.

Application rates should normally be expressed as the quantity of wastewater applied per cycle (see Section 6.4.3(a)). This rate is particularly important for spray systems because high applications may be damaging to the soil surface. The duration of the wetting period should normally not be more than 10 to 12 hours.

Resting or drying periods are necessary to reestablish aerobic conditions in the soil. These drying periods may range from two days to six weeks. The wetting time: drying time ratio should not be larger than 1:4.

The optimum drying period may be determined through pilot studies or from experimentation during the initial operation of the facility. These operating schedules should be flexible because of possible differences in soil characteristics throughout the site. In addition, storms and fluctuations in seasonal ambient temperature may require alteration of the schedule.

Once the application cycle has been determined, the land area should be subdivided into a number of independent plots and a plot rotation schedule established.

The hydraulic application rate for each plot can be described by the following equation:

$$I = 0.01 W/TA_i \quad (6)$$

in which I = application rate (cm/hr)

W = required rate of removal of plant wastewater and stored effluent (m^3 /day)

T = duration of the wetting period (hr)

A_i = area covered during each wetting period (ha/day)

A_i can be described by the following equation:

$$A_i = A/C_i \quad (7)$$

in which C_i = length of the irrigation cycle (days)

A = total land area (ha) (see Section 6.4.4)

Values of C_i and T should be selected such that the following conditions hold:

T less than 10 to 12 hr,

C_i greater than four to five days.

The hydraulic application rate (I) should not be greater than the allowable rate determined through pilot study.

Typical application rates are 0.41 to 0.64 cm/hr (0.16 to 0.25 in/hr).

6.4.6 Determination of buffer zone requirements

When the spray irrigation facility is located near populated areas, a buffer zone is recommended, especially downwind of the sprinkler. In some cases, this may involve scheduling the location of application such that the buffer zone downwind of the application site is a portion of the field.

In other cases, buffer zones from 15 to 60 m wide around the perimeter of the site have been utilized. Provincial regulations may require buffer zones in excess of these.

6.4.7 Land forming requirements

Land forming requirements for spray irrigation are usually minimal. Slope and topographical limitations for spray irrigation were discussed earlier (Section 6.3.1).

Earthwork may be required to divert precipitation and snow melt runoff to a storage basin. Aspects of storage requirements are discussed later in this section.

6.4.8 Underdrainage effluent collection

A subsurface drainage system may be required to prevent the water table from rising into the root zone. The system may consist of wells, buried drain lines or open drainage ditches. Buried drain lines of concrete, tile or plastic are usually used. Inflow into the line occurs between joints in the concrete tile and through slits or holes in the plastic line.

Spacing of the drainage system will be controlled by permeability and depth of wetted material. Procedures for designing drainage systems are usually based on local field experience and assistance may be available from provincial agricultural engineers. These procedures are not discussed in this manual.

Careful consideration of underdrainage requirements for land application is a necessity and normally field investigations are required to specify underdrainage spacings and depth even in preliminary studies. Considerably more detailed investigations, including pilot studies, are required before the final design can be completed.

Figure 19 illustrates the use of an underdrainage system to control the groundwater table, while Figure 20 illustrates the use of a runoff collection system.

6.4.9 Storage requirements

Storage requirements will be a function of climate. The following four conditions would necessitate storage:

- 1) seeding and harvesting the cover crop,
- 2) precipitation requiring the temporary reduction or cessation of application,
- 3) winter weather requiring reduction of winter application rates,
- 4) winter weather requiring cessation of operation.

When cessation of operation resulting from winter weather is expected, storage requirements should be based on the maximum expected period on non-operation. Provincial regulatory requirements may dictate the required storage time.

In the absence of regulatory controls on winter storage requirements, climatic data can be used to determine the severity of frosts and length of time of frozen ground conditions and snow cover. Although several spray irrigation facilities are being operated during frozen ground conditions (see Section 9), a storage basin must be provided to contain the runoff during spring melt of the ice banks.

Temporary wastewater storage may often be necessary when large amounts of precipitation prohibit normal application rates.

The storage requirements can be described by the following relationship:

Storage requirement = wastewater + precipitation - evapotranspiration.

The following assumptions can be made for a system requiring winter storage:

- 1) evapotranspiration is negligible during the winter months;
- 2) the ground is frozen and therefore precipitation must be collected as runoff during snow and ice melt;

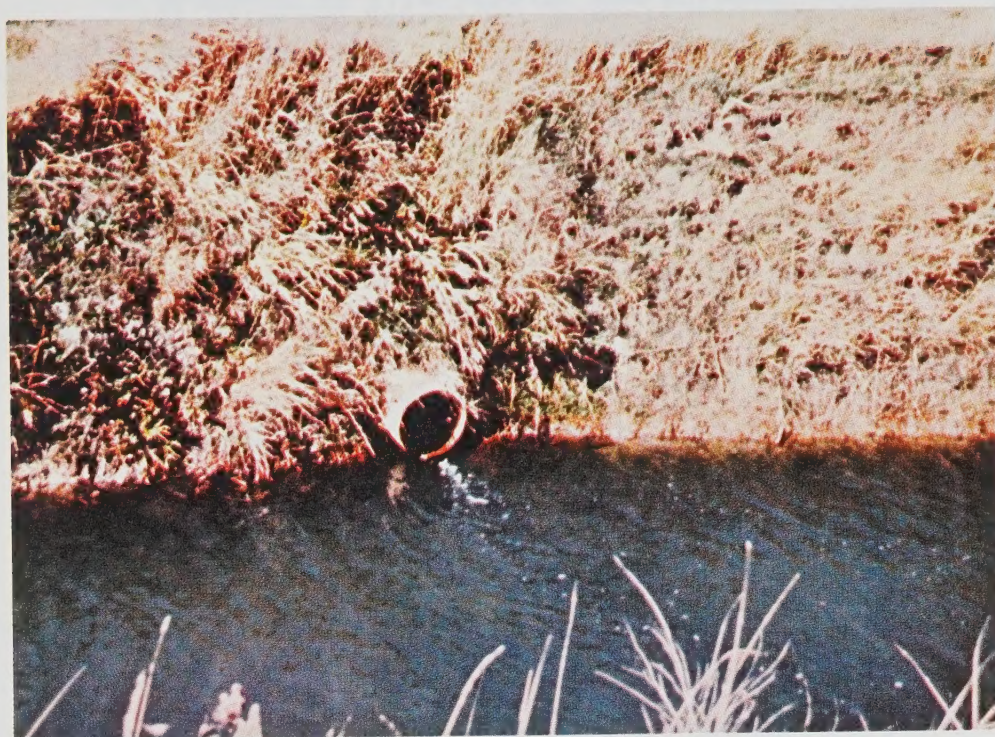


FIGURE 19. UNDERDRAINAGE PIPE AND EFFLUENT COLLECTION DITCH



FIGURE 20. A RUNOFF COLLECTION DITCH

- 3) the storage basin required for winter disposal and/or storage of wastewater during crop seeding and harvest will be adequate to handle temporary storage in summer resulting from excessive rainfall.

A frequency analysis of precipitation data as obtained from the Atmospheric Environment Service should be used to determine the design annual precipitation. The data will be expressed as the maximum precipitation values having a return period of a given number of years (that is, the wettest year in a given number of years).

Unless otherwise specified by provincial regulations, the wettest year in 50 should be used in the design.

The following equation can be used to calculate winter precipitation storage requirements:

$$P = 100P_T \cdot M \cdot A \quad (8)$$

in which P = precipitation storage requirements (m^3),

P_T = average monthly precipitation (cm/months),

M = length of the storage period (months),

A = total land area being irrigated (ha).

The expected wastewater production during winter can be combined with the value of P from equation (8) to calculate total storage requirements according to the following equation:

$$S = P + W \quad (9)$$

in which S = total storage requirements (m^3),

W = wastewater production during winter months (m^3).

For seasonal food processing plants which do not require winter storage, a storage basin should be provided for wastewater during low intensity, long duration rainfall. A basin designed to handle a two-week wastewater production will be adequate.

It is a valid assumption that the volume from rainfall runoff will be negligible compared to the volume of wastewater. The total storage requirement is therefore equivalent to a two-week wastewater production.

6.4.10 Distribution system design

For detailed design of spray irrigation systems, reference is made to a sprinkler irrigation handbook such as that by Pair [20] for hydraulic-design information. The purpose of this section of the manual is to discuss briefly the major components of a spray irrigation system and to outline some general practices used in spray irrigation.

The distribution system for spray irrigation consists of four elements:

- transmission to site,
- distribution to outlets,
- outlet configuration,
- controls.

Transmission to the site can be by pressure or by gravity. Velocities in the transmission main should be between 2.5 and 3 m/s. Gravity mains should be at the low end of the range and force mains should be in the middle to upper range. Where velocities are too high, excessive losses occur at bends and valves.

Spray distribution systems may be either fixed or movable. Fixed sprinkling systems, often called solid set systems, may be either on the ground surface or buried. Both types usually consist of impact sprinklers on risers that are spaced along lateral pipelines, which are in turn connected to main pipelines. Figure 21 illustrates a main, lateral, flow control valve and couplings in a typical solid set, above ground spray distribution system.

Above ground systems normally use portable aluminum pipe; it has a relatively low capital cost. Plastic or asbestos-cement pipe is most often used for buried systems. Laterals may be buried as deep as 45 cm (1.5 feet), and the main pipelines 80 to 90 cm (2.5 to 3 feet) below the surface.

Once an acceptable irrigation application rate, I , has been selected, a sprinkler spacing should be selected (that is, the distance between laterals and between the sprinklers on each lateral). Typical spacings are 20 m by 25 m (60 ft by 80 ft) and 25 by 30 m (80 by 100 ft). An exception is a system using rain guns for which the spacing may



FIGURE 21. AN IRRIGATION MAIN, LATERAL AND FLOW CONTROL VALVES

be 60 by 60 m (200 by 200 ft). The lower spacing is used in those areas where high velocity winds are frequent or where aerosol drift may present problems. Typical layout of a sprinkler irrigation system is illustrated in Figure 22.

When the application rate and wetting area for each sprinkler have been determined, nozzles are chosen to distribute the wastewater. Nozzles generally vary in size from 6 to 25 mm (0.25 to 1.0 inch). Discharge per nozzle can vary from 1 to 27 m³/hr (4 to 100 l/gpm) for conventional sprinkler nozzles (typical is 8 to 25 l/gpm) to 81 m³/hr (300 gpm) for rain guns. Application may be low pressure (35 to 210 kN/m²), medium pressure (210 to 415 kN/m²) or high pressure (greater than 415 kN/m²); rain guns typically operate at pressures of 1035 kN/m².

Sprinklers are mounted on risers which may be galvanized pipe or PVC of sufficient height to clear the cover crop. Risers in excess of 1.2 m (4 ft) should be supported since impact sprinklers cause vibrations that must be dampened.

TYPICAL SYSTEM LAYOUT

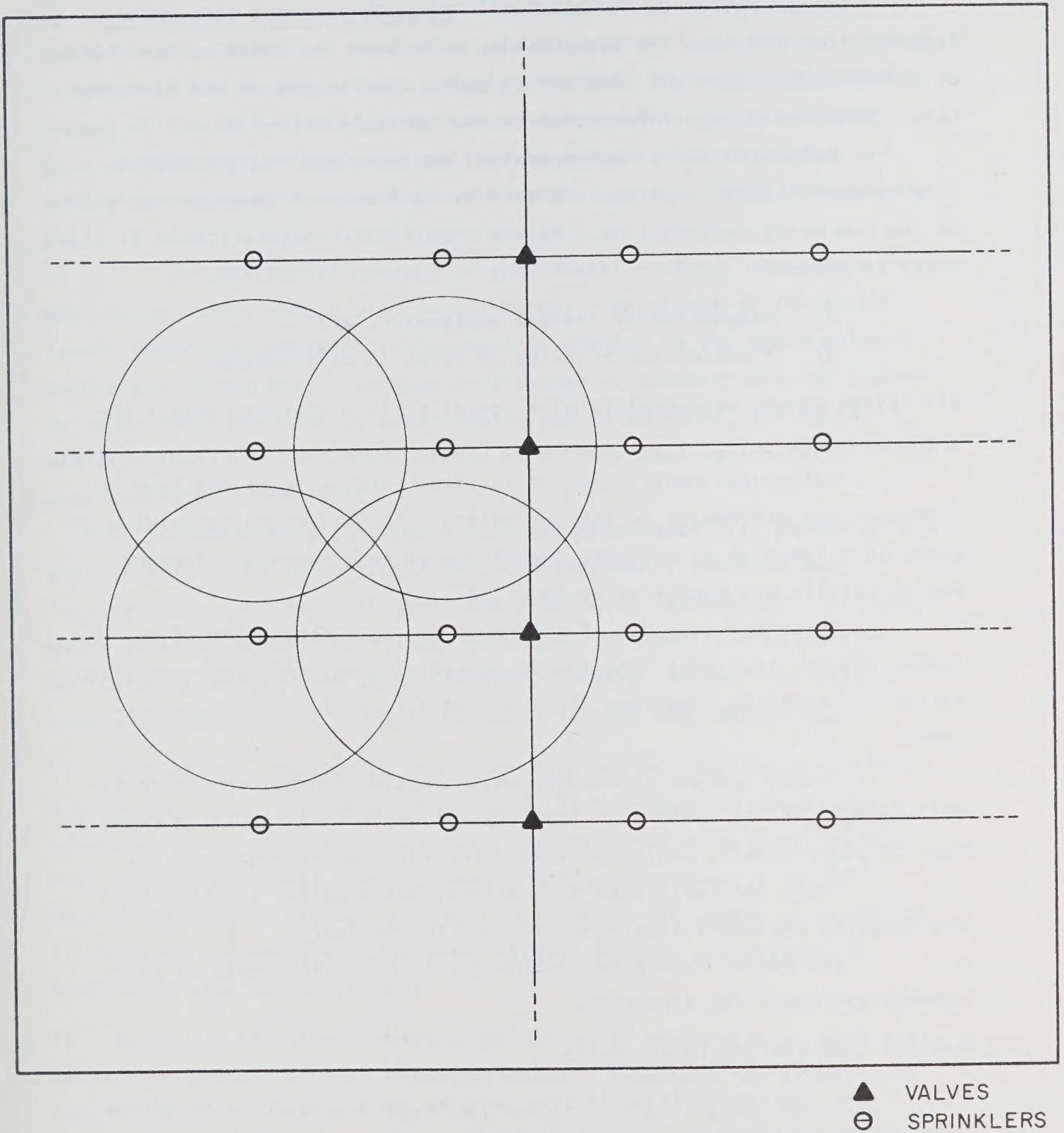


FIGURE 22. SOLID SET SPRINKLER IRRIGATION.

Distribution to the nozzles is through pressure pipes or laterals that run from the transmission main into the field. The design of transmission mains and laterals is quite complex and is not discussed here. Detailed design information is available in Pair [20].

Valves, usually hand operated, are required to control the flow to each lateral. Laterals should be laid so that these valves will be the low point in each line. Valves should drain automatically in order to prevent:

- a) stagnation of trapped wastewater, and
- b) freezing and breaking of pipes in cold weather.

All valves should be underlain with gravel or tile drain to accept the drained water.

Horizontal centrifugal or vertical turbine pumps are used to transport the wastewater to the sprinklers. The selection and sizing of pumps is a function of pressure and discharge requirements. Further design details are discussed by Pair [20].

There are a number of different moving systems, including center pivots, side roll, wheel move, rotating boom, and winch-propelled sprinkling machines. Designs are provided by suppliers of these systems.

Backup systems or standby units should be provided for critical elements of the systems to preclude system failure resulting from loss of power supply, equipment failure or maintenance requirements.

Plans for facilities such as monitoring wells, sampling taps and metering equipment should be included in the design.

The design should be concluded with the development of maintenance and operating schedules.

6.4.11 Monitoring requirements

A comprehensive monitoring program may be required to ensure that proper wastewater treatment is being carried out and that environmental degradation is not occurring. Groundwater, treated water, vegetation and soils may have to be monitored.

a) Groundwater and treated water. Groundwater or recovered water (water from underdrains) monitoring may be required. Generally, nitrate nitrogen is the parameter most closely observed. To assess the overall impact of the system, changes in groundwater quality can be compared with the quality of background wells. An example of a compliance and operational monitoring schedule which may be required is illustrated in Table 15.

In addition to changes in groundwater quality, changes in groundwater level should also be monitored. The effect of increased levels should be assessed with respect to changes in the hydrogeologic conditions of the area. Changes in groundwater movement and the appearance of seeps and perched water tables should be noted, and system modifications, such as underdraining or reduced application rates in the area should be undertaken.

Monitoring requirements for recovered water will depend on its end use. If it is to be discharged, the parameters analyzed must include those required by Federal and Provincial regulations. If the water is to be reused, additional parameters as specified by public health agencies may need to be analyzed. Monitoring the flow rate of recovered water may be required for water rights considerations.

b) Vegetation. Monitoring the cover crop may be required to optimize growth and yield. Although conventional farm management techniques normally apply, special factors must be considered because of the normally higher hydraulic loading rates. For some systems, a detailed monitoring program may be required to determine the uptake of potentially toxic constituents such as heavy metals, if they are present in abnormally high concentrations.

c) Soil. In almost all cases, application of wastewater to land will cause some changes in soil characteristics. Important characteristics include salinity levels of various elements, pH and cation exchange capacity.

TABLE 15 EXAMPLE OF OPERATIONAL AND COMPLIANCE
MONITORING SCHEDULE FOR AN IRRIGATION SYSTEM [21]

Parameter ^a	Sampling Frequency at Various Points				
	Applied Effluent	On-site Wells (3 Points)	Background Well (1 Point)	Perimeter Wells (5 Points)	Adjacent Lake (1 Point)
BOD ₅	D	-	-	-	Q
COD ^b	M ^c	Q	Q	Q	Q
Chlorine residual	2D	-	-	-	-
Coliform, fecal	M	Q	Q	Q	Q
Coliform, total	D	Q	Q	Q	Q
Flow	C ^d	-	-	-	-
Nitrogen ^e	M ^c	Q	Q	Q	Q
pH	2D ^d	Q ^d	Q ^d	Q ^d	Q ^d
Phosphorus	M ^c	Q	Q	Q	Q
Suspended solids	D	-	-	-	-
Static water level	-	M ^d	M ^d	M ^d	-

Note: D = One sample or measurement per day

Q = One sample or measurement every three months

M = One sample or measurement per month

2D = Two samples or measurements per day

C = Continuous measurement and recording

^a If filtered samples of raw wastewater demonstrate the concentration of a particular health-significant parameter (not given above) to be in excess of the permissible limit for drinking water sources, that parameter will be included in this schedule.

^b May also use TOC to establish a long term correlation with BOD₅.

^c Denotes samples to be 24-hour composites. All others are grab samples.

^d Field measurement.

^e Total nitrogen for effluent; nitrate-nitrogen for groundwater.

The salinity of the soil, as measured by electrical conductivity, may be of some concern in arid regions because of its injurious effect on plants. Remedial action includes leaching or underdrainage.

Metal elements of concern include sodium adsorption ratio (discussed in Section 3), nitrogen, phosphorus, potassium, magnesium, boron and heavy metals.

Optimum soil pH for retention of most wastewater constituents is the range pH 6-7. Wastewater should be pH adjusted prior to application. If decrease in soil pH still occurs, it may be corrected by the addition of lime.

Cation exchange capacity (discussed in Section 2.1.2) is an important parameter because of its role in the chemical treatment of wastewater. The exchange sites may be occupied by ammonium, calcium, magnesium, sodium and hydrogen ions. The change in percent of available sites occupied by each cation is the important trend to monitor. For example, if there is excessive build-up of sodium, remedial measures such as the addition of gypsum should be considered.

6.5 Flooding

6.5.1 Introduction

As discussed in section 6.2.1, flooding by border dike strip, contour check, or spreading basin is a second method of irrigation application. Caution should be exercised when applying this method for treatment of food processing wastewater, especially when a cover crop is used. Suspended solids may be deposited at the head end of the strip or basin, overloading that area and choking out the vegetation. Flooding methods are best suited to systems that are operated as infiltration basins without vegetated surfaces.

The major design variables for surface flooding systems include strip dimensions, distribution method and application rates. Many of the design criteria discussed below are similar to those for spray irrigation systems. Reference to the subsection on spray irrigation has been made at appropriate points.

6.5.2 Pretreatment requirements

(See Section 6.4.1).

6.5.3 Cover crop selection

Cover crops selected for flood irrigation must be able to withstand periodic inundation with wastewater. Sod crops are most suited to flood irrigation.

6.5.4 Loading rate determination

a) Hydraulic loading rate. Methods of determining allowable seasonal and cyclic hydraulic loading rates are discussed in Section 6.4.3(a). The wetting or flooding depth should not exceed 5 to 7 cm (2 to 3 inches) to avoid long term flooding.

b) Organic loading rate. The organic suspended solids in food processing wastewaters may significantly alter soil infiltration rates and thus control the allowable loading rate. Application rates which cause clogging of the soil surface under anerobic conditions (caused by prolonged inundation) must be avoided. The "aerobic" or resting period is very important in flood irrigation systems.

The allowable organic loading rate cannot be predicted but must be determined from pilot studies.

c) Nutrient loading rate. (See Section 6.4.3(c)). The nitrification-denitrification process may be a significant mechanism for nitrogen removal in a flood irrigation system. The rates must be determined from pilot studies.

d) Inorganic loading rate. (See Section 6.4.3(d)).

6.5.5 Selection of limiting loading rate

(See Section 6.4.4).

6.5.6 Determination of hydraulic application rates and irrigation schedules

Methods of determining the application rate and length of the irrigation cycle are similar to those discussed in Section 6.4.5. Application rates must be determined from pilot studies. They will vary

with soil type and may range from 8 to 18 m³/hr (30 to 65 lgp) per metre of strip for clay to 45 to 63 m³/hr (160 to 230 lgp) per metre width for sand.

The resting period is usually between 6 and 14 days.

6.5.7 Buffer zone requirements

(See Section 6.4.6).

6.5.8 Land forming requirements

Land forming is usually required to form flooding basins or strips of required slope. Flooding basin strips vary with type of crop, type of soil, and slope. Border width may range from 6 to 30 m (20 to 100 feet); 12 to 18 m (40 to 60 feet) widths are the most common. Slopes range from 0.2 to 1.0 percent. The steeper slopes are required for relatively permeable soils. Strip lengths may vary from 180 to 420 m (600 to 1400 feet).

For good distribution, the water should reach the end of the field in about one quarter of the total irrigation time.

The land is formed so that each strip is separated from adjacent ones by low levees or borders. The surface should be level between levees so that the advancing sheet of water covers the entire width of land strip; the surface will slope longitudinally depending on the natural slope of the land.

Levees should be from 2 to 2.5 m (6 to 8 feet) wide at the base and not over 30 to 45 cm (12 to 18 inches) high since it is essential to avoid obstruction to farm machinery.

6.5.9 Underdrainage effluent collection

(See Section 6.4.8).

6.5.10 Storage requirements

(See Section 6.4.9).

6.5.11 Distribution system design

As in a spray irrigation system, the distribution system consists of transmission to site, distribution to outlets, outlet configuration and controls. Similar methods of wastewater transmission to

the site are used but distribution at the site is generally by means of concrete-lined ditches with slide gates at the head of each strip or by means of gated aluminum pipe.

Flood irrigation is not very easily adapted to automatic flow control and labour requirements for flow distribution are usually higher than they are for spray irrigation systems.

6.5.12 Monitoring requirements

(See Section 6.4.11).

6.5.13 Cover crop management specifications

(See Section 6.4.12).

6.6 Ridge and Furrow Irrigation

6.6.1 Introduction

The ridge and furrow method (described in Section 6.2.1(a)) is best suited to smaller systems where close control of large wastewater volumes is not required. Level or gently sloping land is required for ridge and furrow irrigation. The soil should be relatively permeable in order to reduce the amount of surface clogging that may occur because of the deposition of solids.

6.6.2 Pretreatment requirements

(See Section 6.4.1).

6.6.3 Cover crop selection

Row crops are most suited for ridge and furrow applications. Spacing of furrows for corn, potatoes, sugar beets and other row crops is determined by the proper spacing of the plant rows, one irrigation furrow being provided by each row. Small grain and sod crops may be irrigated by this method, using small furrows. This system may be advantageous when the available irrigation flows are small or when the land is undulating.

6.6.4 Loading rate determination

a) Hydraulic loading rate. Methods of determining allowable seasonal and cyclic hydraulic loading rates are discussed in Section 6.4.3(a). Although the length of inundation within each furrow is not critical, prolonged saturation of the ridges must be avoided.

b) Organic loading rates. The organic suspended solids in the wastewater are critical to the operation of a ridge and furrow system. Clogging of the furrow walls will usually occur if the wastewater has not undergone pretreatment. Clogging would require relocation of ridges and furrows in order to allow aerobic "recovery" of the soil. The problem may be alleviated, however, by allowing the furrows to dry out after each application so that the soil pores do not become clogged.

The length of the operational periods before clogging occurs must be determined through laboratory soil column experiments or field pilot studies.

c) Nutrient loading rate. (See Section 6.4.3(c)).

d) Inorganic loading rate. (See Section 6.4.3(d)).

6.6.5 Selection of limiting loading rate

(See Section 6.4.4).

6.6.6 Determination of hydraulic application rates and irrigation schedules

Methods of determining the application rate and the irrigation cycle are similar to those discussed in Section 6.4.5. Application rates must be determined through pilot studies; these will vary with the type of soil, cover crop and furrow spacing.

The resting period is usually between 6 and 14 days.

6.6.7 Buffer zone requirements

(See Section 6.4.6).

6.6.8 Land forming requirements

Any ridge and furrow system requires a large amount of land forming relative to spray irrigation. Level or very gently sloping land

is required for ridge and furrow irrigation to be effective. Furrow slopes of 0.5 to 3% are preferable.

Land forming is required to dig the furrows whose depth and spacing are dependent on soil conditions and type of cover crop. In forestland, these furrows may be anywhere from 0.9 to 1.8 m (3 to 6 feet) apart. If row crops are being grown, the furrow spacing is determined by proper spacing of the plant rows.

Furrows from 20 to 30 cm (8 to 12 inches) deep are most suitable for soils of low permeability while shallow furrows 8 to 13 cm (3 to 5 inches) deep may be more suitable for very permeable soils with a row crop.

Furrow lengths should be limited to 90 to 200 m (300 to 660 feet). Excessive percolation losses and soil erosion near the upper end of the field result from the use of very long furrows.

6.6.9 Underdrainage effluent collection

(See Section 6.4.8).

6.6.10 Storage requirements

(See Section 6.4.9).

6.6.11 Distribution system design

Labour requirements for ridge and furrow application are usually minimal. Once the wastewater has been conveyed to the head of each furrow, distribution occurs by gravity flow.

The design of facilities for wastewater transmission to the site is similar to the procedure discussed in Section 6.4.10.

Water may be distributed to the furrows from supply ditches, concrete flumes, or gated aluminum pipe (Figure 23).

6.6.12 Monitoring requirements

(See Section 6.4.11).

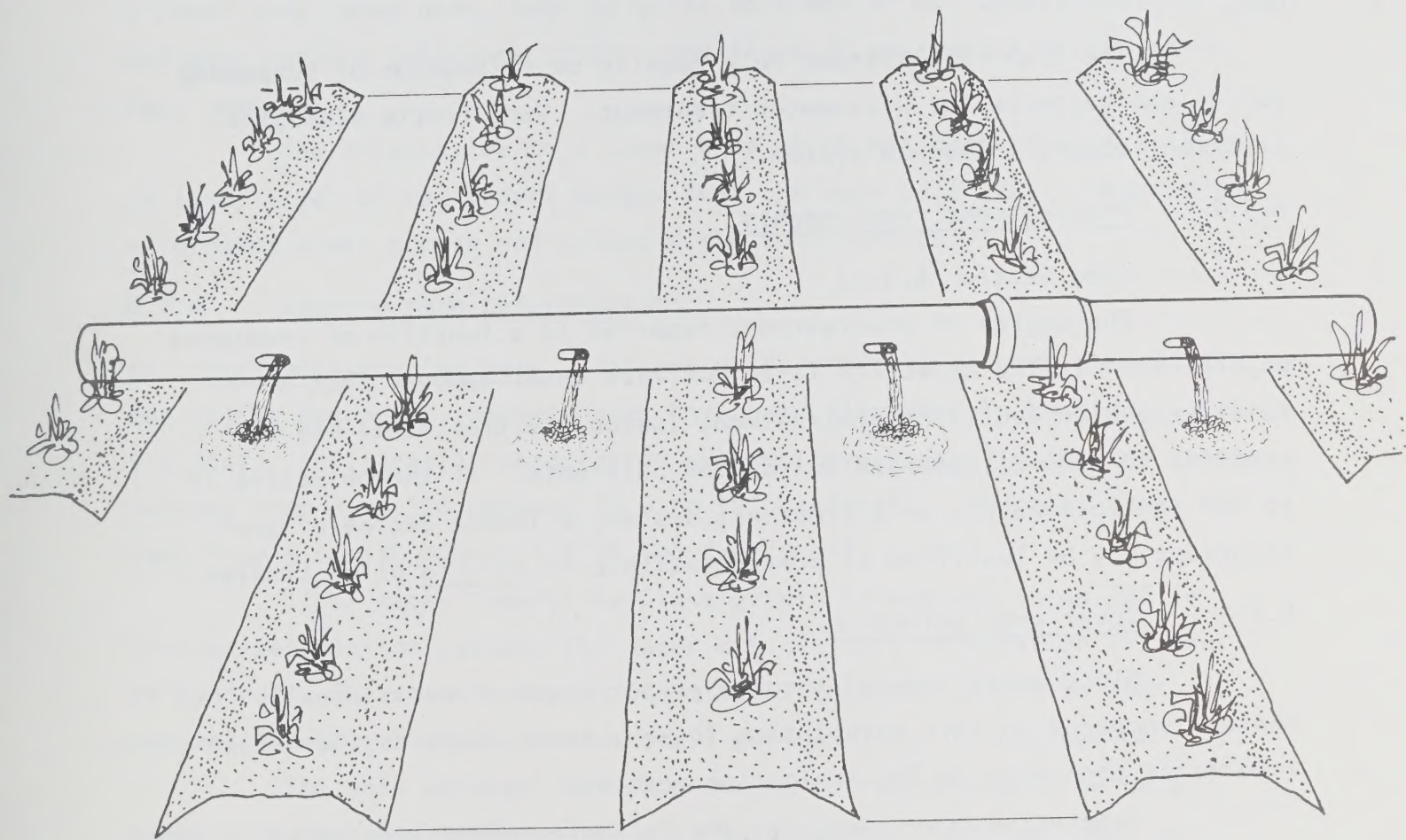


FIGURE 23. PORTABLE GATED ALUMINUM PIPE DELIVERING WATER TO FURROWS.

6.7 Infiltration-Percolation

6.7.1 Introduction

Rapid infiltration and subsequent percolation of wastewater through the soil profile characterize this treatment method. High rate systems are those that remove more than 1.5 m (5 feet) of wastewater per week while moderate rate systems remove less than 1.5 m (5 feet) per week.

The high rate systems rely heavily on filtration of suspended solids and bacteria for wastewater treatment. Very little biological treatment occurs in such a system.

6.7.2 Pretreatment requirements

(See Section 6.4.1)

The degree of pretreatment required is a function of treatment objectives. If the objective is to maximize water removal then a relatively high degree of pretreatment (secondary treatment) may be required to remove suspended solids and nutrients. If the objective is to use the soil matrix as a treatment system, a lesser degree of pretreatment may be justified if proven feasible by in situ pilot studies.

6.7.3 Cover crop selection

Since water removal through evapotranspiration is usually minimal compared to soil percolation losses, cover crops assume lesser importance than they do for irrigation methods.

Vegetative cover provides the following advantages in an infiltration-percolation system:

- 1) root channels which increase the hydraulic capacity of the soil;
- 2) protection of the soil surface from the impact of water droplets;
- 3) a small amount of nutrient removal if the vegetation is harvested.

The disadvantages of a cover crop include the following:

- 1) increased maintenance;

- 2) loading cycles must be adjusted to promote plant growth at the start of the growing season and to permit harvesting;
- 3) loading rates must be adjusted to prevent prolonged inundation of plant roots.

A cover crop, when used, must be quite tolerant of wet conditions. It may also require tolerance to dry conditions if wastewater discharge is very seasonal.

One alternative to a cover crop which has been used is a 15 cm (6 inch) layer of pea gravel spread over the bare soil [22]. This layer eliminates plant growth and protects the soil surface.

6.7.4 Loading rate determination

a) Hydraulic loading rate. Methods of determining allowable seasonal and cyclic hydraulic loading rates have been discussed in Section 6.4.3(a). Infiltration-percolation systems have hydraulic loading rates varying from 9 to 300 cm/week (0.3 to 10 feet/week). Seasonal rates may vary from 5 to 150 m/year (18 to 500 feet/year).

Since water removal by plant growth is minimal in an infiltration-percolation system, the water deficit term in Equation (1) can be ignored. The water removal potential is then equivalent to the removal through soil percolation (soil permeability, P in equation (1)).

The soil permeability rate during operation should be determined through pilot studies. This is particularly important when applying wastewater which is high in suspended solids. In these systems, the infiltration rate may become limiting because of clogging of the soil surface.

b) Organic loading rate. The organic suspended solids in food processing wastewater may alter significantly the infiltration rate and thus control the allowable loading rate. Application cycle and resting periods must be optimized to prevent permanent soil clogging.

c) Nutrient loading rate. Nutrient loading rates are very important in infiltration-percolation systems since very few nutrients are removed either by vegetative growth or by soil fixation processes. The lower

clay and organic content of soils suitable for infiltration-percolation results in lower fixation capacity for ammonium and phosphate ions.

These conditions may lead to significant leaching of nitrogen and phosphorus to groundwater. The addition of nitrogen to groundwater may be minimized by biological pretreatment or by using application schedules which promote nitrification-denitrification.

Pilot studies should be conducted to determine allowable nutrient loading rates to the soil, especially if the groundwater table is less than 4.5 m (15 feet) from the surface.

d) Inorganic loading rate. The inorganic minerals of concern in infiltration-percolation systems are primarily those which decrease groundwater quality. These include phosphorus, nitrogen, heavy metals and boron.

The limiting concentrations have been summarized in Section 6.4.3(d).

6.7.5 Selection of limiting loading rate.

(See Section 6.4.3(d)).

6.7.6 Determination of hydraulic application rates and irrigation schedules

Methods of determining application rates and irrigation cycles are similar to those discussed in Section 6.4.5. Application rates can be estimated from soil permeability tests and verified by in situ studies. Typical rates have been discussed in Section 6.7.4(a).

The loading cycle generally varies in length from nine hours to two weeks. Drying periods are usually one day to three weeks in duration.

6.7.7 Buffer zone requirements

(See Section 6.7.6).

6.7.8 Land forming requirements

Infiltration-percolation usually consists of flooding in basins. Basin size is generally a function of design flow and the relationship between wetting and drying periods. Basin sizes may range

from less than 0.4 ha to 4 ha or more (1 to 10 acres). It is usually necessary to construct at least two basins, even for the smallest systems. While one basin is being used, the other can be dried and rejuvenated.

Dikes must be built around the basins to prevent runoff. The height will vary with the depth of water applied. Common wastewater inundation depths are 30 to 60 cm (1 to 2 feet). In such cases, a dike height of 1.2 m (4 feet) is common.

6.7.9 Underdrainage effluent collection

The design of underdrainage systems has been discussed in Section 6.4.8. Underdrainage for infiltration-percolation systems may be required to prevent excessive groundwater buildup or to intercept the effluent and collect it for further treatment prior to discharge.

6.7.10 Storage requirements

Storage facilities are not usually required to store effluent during excessive rainfall. Storage facilities may, however, be required for winter storage of effluents. The design criteria for these facilities have been discussed in Section 6.4.9.

6.7.11 Distribution system design

The distribution system consists of facilities to transfer wastewater to the site, outlet facilities and hydraulic controls.

As in irrigation systems, transmission to the site can be by gravity or by pumping. The outlet facilities usually consist of a single riser pipe in each basin. High rate spray application may also be used. Since the basin flooding technique is used, special equipment is not required for spray application systems.

Distribution to the site is usually via a single pipe from the transmission main. If the velocities are too high when using one pipe, a diffuser system of two or three outlets can be used. Erosion is minimized at low velocities. A concrete splash pad is recommended at the outlet to distribute the flow.

6.7.12 Monitoring requirements

Groundwater monitoring is important for infiltration-percolation systems. Sampling wells should be established around the site on the basis of geological data. Groundwater or percolate water quality should be monitored for BOD₅, suspended solids, nitrogen, phosphorus and total dissolved solids. The condition of basin surfaces should be monitored regularly. Where bare soil or gravel surfaces are used, they should be sacrificed or raked when solids accumulate. The frequency will depend on wastewater quality. Methods used have included shaving or sweeping, disking, scarifying and rototilling.

Basins with cover crops should also be observed regularly to ensure that there is not excessive inundation and/or drying. The soil surface may require scarifying annually to break up any solids.

6.8 Overland Flow

6.8.1 Introduction

The overland flow method takes advantage of the low permeability properties of heavy soils. This method was developed at the Campbell Soup Company plant at Napoleon, Ohio in 1954. It was found that runoff from spray application was receiving a high degree of treatment after moving down relatively steep slopes. This principal of grass filtration has subsequently been refined through experience at several other overland flow or spray runoff installations.

Overland flow differs from spray irrigation primarily in that a substantial portion of the wastewater applied appears as runoff which must be collected and discharged to receiving wastes or stored for further treatment.

6.8.2 Pretreatment requirements

(See Section 6.4.1).

6.8.3 Cover crop selection

The cover crop is an essential component of an overland flow system. It prevents soil erosion, provides nutrient uptake and most importantly, serves as media for the biological treatment of the waste-

water. It has a function similar to rock or plastic media in a conventional trickling filter.

Perennial sod crops (grasses) with long growing seasons, high moisture tolerance and extensive root formation are best suited for this application. Reed canary grass has a very high nutrient uptake capacity and yields a high quality hay. Other grass crops used include rye grass and tall fescue.

6.8.4 Loading rate determination

a) Hydraulic loading rate. In contrast to infiltration percolation systems, soil characteristics are not as important as climatic and cover crop factors in determining the water removal capacity. A small portion of the water percolates into the soil but may only be removed by evaporation from the soil surface and by transpiration from the cover crop. Some of the applied wastewater will be runoff which must be collected and discharged with or without further treatment.

Procedures for determining the maximum seasonal wastewater loading rate, R_w , were discussed in Section 6.4.3(a). Equation (1) does not account for water removal by runoff. It must be modified as follows:

$$R_w = P + D/10 + S_R \quad (10)$$

in which S_R = seasonal runoff rate (cm/yr)

P = soil permeability (cm/yr)

D = water deficit (mm/yr)

The value of S_R can be obtained from pilot studies. Runoff values typically range from 40% in the summer to 80% in the early spring and late fall based on effluent plus percolation [23, 24, 25]. These values can be used in preliminary design but actual values should be confirmed by pilot studies since the 40% to 80% range is based on experience in warmer climates.

Equation (3) can be used to determine the total land area required. The value of Q must be modified to include recycled water where applicable. Water collected as runoff must be further treated if it does not meet effluent requirements for direct discharge. Treatment may be accomplished by recycling a portion of the runoff to the top of

the slope or by providing additional facilities. Where runoff recycle is used, the rate of recycle and seasonal variations must be determined from pilot studies. This modified value of Q can then be used to determine the total land area requirements.

The allowable loading rate during each application period must also be modified to include runoff. Wastewater removal by infiltration generally will be 0.3 cm/day (0.1 in/day) or less. A significant percentage of the water may also be removed by evapotranspiration during the active growing season.

Typical application rates used in overland flow systems range from 0.15 cm/hr to 0.3 cm/hr (0.05 to 0.1 in/hr).

b) Organic loading rate. The limits of organic loading have not been well defined since the organic matter is filtered out and is further reduced by biological oxidation; organic content of the soil is not significantly increased. High organic loadings may, however, limit treatment efficiency as a result of the combined effects of BOD_5 and liquid loading on the creation of anaerobic conditions. Applications must be scheduled to avoid these conditions.

High strength organic wastes have been treated at BOD_5 loadings of 45 to 112 kg/ha/day (40 to 100 lb/acre/day).

c) Nutrient loading rates. Nutrient removal in overland flow systems occurs through crop uptake, microbial uptake and soil fixation. Since only a small portion of the wastewater enters the soil, soil fixation processes do not provide a significant means of phosphorus removal. Additional treatment of runoff for nutrient removal prior to effluent discharge may be required even in a properly functioning system. The need for such facilities should be assessed through pilot studies.

Principles of nutrient removal have been discussed in Section 6.4.3(c). Equations (4) and (5) can be used once suitable values of R_n and R_p have been determined.

d) Inorganic loading rate. (See Section 6.4.3(d)).

6.8.5 Selection of limiting loading rate

(See Section 6.4.4).

6.8.6 Determination of hydraulic application rates and irrigation schedules

(See Section 6.4.5).

Wastewater application must be programmed to maintain active soil microorganisms. The application period must be sufficiently short to avoid the development of anaerobic conditions.

Typical values of T are six to eight hours and typical values of C_i are 0.67 to 0.75 days (16 to 18 hours).

6.8.7 Determination of buffer zone requirements

(See Section 6.4.6).

6.8.8 Land forming requirements

Surface alterations may be required to provide adequate slope and soil surface characteristics. Optimum slopes for overland flow may range from 2 to 8 percent with 2 to 4 percent defined as optimum for adequate detention time. Slope lengths vary from 45 to 90 m (150 to 300 feet) with 53 to 76 m (175 to 250 feet) being typical. Longer slopes may be required for spring and fall operation because of the lower microbial growth rates. In order to prevent erosion and to allow uniform flow, slopes must be uniform in cross slope and free from gullies.

In order to provide an adequate seed bed for the cover crop, care must be taken to re-establish topsoil on constructed slopes.

A network of ditches must be constructed to intercept the runoff and to channel it to the point of discharge or storage. The ditches must be graded to prevent erosion but they must have sufficient slope to prevent ponding in low spots. They also must be adequately sized to accept the added flow from rainfall runoff.

6.8.9 Underdrainage effluent collection

Since infiltration into the soil is minimal, the effects of the system on groundwater are minimal. The depth of the groundwater below the soil surface must be sufficient to avoid impact on the growth of the cover crop. Where this condition does not exist, groundwater drainage may be required. Principles of design have been discussed in Section 6.4.8.

6.8.10 Storage requirements

The winter storage requirements for irrigation systems have been discussed in Section 6.4.9. Similar assumptions and procedures should be used for overland flow systems.

For those systems which are seasonal and do not require winter storage, facilities should be provided to collect rainfall. In contrast to irrigation system design, rainfall runoff may be significant in overland flow systems.

Rainfall storms are the major factor in determining storage requirements. Unless otherwise specified by regulations, the total recorded rainfall in a 24-hour storm with a 50-year recurrence interval should be used to determine rainfall storage requirements.

The following equation can then be used to calculate effluent storage requirements.

$$S = W + 100PA \quad (11)$$

where: S = total storage requirement (m^3),
 W = wastewater production during storage period (m^3),
 P = precipitation storage requirement (cm),
 A = total land area being irrigated (ha).

For the definition of terms see Section 6.4.9.

6.8.11 Distribution system design

Spray irrigation is the most common method of application for overland flow treatment. Wastewater is applied on the upper reaches of the slope and allowed to flow downhill. Spraying may be accomplished by fixed sprinklers or rotating boom sprayers. Equipment design for spray irrigation systems is discussed in Section 6.4.10.

The following aspects must be carefully considered:

- 1) Sprinklers should be located such that their spray diameter covers approximately the upper one-third to two-thirds of the slope.
- 2) The sprinkler setting must permit overlap for efficient area coverage (for example a sprinkler spacing of 9 m for a spray diameter of 12 m).

- 3) Buried pipes are preferable to portable aluminum pipes; above ground pipes pose a barrier to downslope runoff and may adversely affect distribution.

Surface application methods discussed in Sections 6.5, 6.6 and 6.7 have also been used. They are more suitable for wastewaters with low concentrations of organic solids.

Overland flow systems must also include hardware for the collection of runoff from ditches and transport to the point of discharge. Open gravity flow channels or closed pipe and pumping facilities may be used. The facilities must be sized to handle combined wastewater and rainfall runoff flows.

6.8.12 Monitoring requirements

Monitoring is necessary to maintain loadings within design limits. A routine monitoring program should be established for the following parameters:

- 1) wastewater application rates (m^3/day),
- 2) runoff flow rates (m^3/day),
- 3) wastewater quality, including BOD_5 and COD, suspended solids, total dissolved solids, total nitrogen, total phosphorus, pH and SAR,
- 4) runoff effluent water quality according to the analyses summarized in item (3) above.

Soil and groundwater monitoring are not normally required for overland flow systems since infiltration is minimal.

6.9 Subsurface Leaching

6.9.1 Introduction

Few data exist at present on the treatment of food processing wastes using septic tanks and leaching beds. It is suggested that further study is required before a true assessment of their suitability and design can be made.

A brief review of design criteria for leaching fields for domestic sewage disposal is now given.

6.9.2 System description

The septic tank system was originally developed for isolated households in rural areas. A typical application would be a farm or other rural development with relatively low water usage and hence low wastewater flows.

The system consists of two main parts as shown in Figure 12. These include the septic tank and the tile or disposal field.

a) Septic tank. The septic tank is a watertight covered receptacle designed to receive sewage from a building sewer. Septic tanks treat the wastewater by gravity separation of the solids from the liquid. Anaerobic digestion of the sludge provides further treatment, but the contribution of digestion towards overall treatment is small. Removals of 30 percent to 60 percent BOD_5 and 50 percent to 80 percent suspended solids have been reported.

b) Tile field. The tile field is an excavation in the soil in which clean coarse aggregate and distribution pipe are placed and covered with earth. The mechanisms that achieve effluent purification in tile fields are adsorption, filtration, and biological degradation. The dominant removal mechanism is a function of the pollutant and the soil type. Bacteria are removed by screening, entrapment, gravity forces, coagulation, and flocculation [26]. In addition, enteric bacteria cannot compete with the indigenous soil bacteria and they die off rapidly in disposal field. Disposal tile fields, rather than septic tanks, are the major cause of the failure of septic tank systems. Failure can occur either as pollution of groundwater or as surfacing of effluent.

The physical criteria required for satisfactory use of tile field systems deal with groundwater and geological characteristics of the area and are related to the capability of the soil to assimilate the effluent.

The following criteria were developed by CH₂M Nelson in conjunction with Stanley Associates Engineering Ltd. for the City of Kelowna in 1976 [27]:

- 1) Water table.
- 2) Topography.
- 3) Depth to the impervious soil horizon.
- 4) Presence of soils with excess stoniness.
- 5) Depth to bedrock.

The limiting effects of those criteria are as follows:

1) Water table. When the water table is close to the surface, 1.2 m or less (4 feet or less), pollution of the groundwater may occur.

McGauhey [28] stated that the septic tank system increases the total dissolved mineral content of local groundwaters and at worst may introduce bacteria, viruses, and degradable organic matter.

2) Topography. Steeply sloped sites at or just below the tile field can cause surfacing of the effluent. For example the City of Kelowna has resolved not to install tile fields at sites with slopes exceeding 30%.

3) Depth to dense impervious soil horizon. An impervious soil horizon causes ponding of the effluent. If this is close to the surface, effluent will pond before receiving satisfactory treatment. The partially treated effluent may flow along the impervious soil layer until it reaches a groundwater source, or until it surfaces.

4) Soils with high percolation rates. Soils with high percolation rates do not assimilate the pollutants rapidly and wastewater can reach the groundwater before assimilation occurs.

5) Depth to bedrock. The depth to bedrock can also limit the application of tile fields by creating ponding or surfacing of the effluent before sufficient treatment has occurred.

Some alternative approaches to alleviate the above problems are available. The evapotranspiration bed or "mound" system is one alternative in which the tile field is constructed in a "synthetic" soil system, that is, the tile field is built above the natural ground within permeable soil. Some of the wastewater then percolates through

the soil system and is treated before reaching the groundwater; the remainder is removed by evapotranspiration to the atmosphere.

6.9.3 Recommendations

It is apparent from a review of available literature that the use of septic tank systems for domestic wastewater treatment is restricted primarily to single dwellings. They have found limited application in the treatment of food industry wastes and have been used primarily where low volumes of wastewater are generated such as in meat and poultry rendering plants. Limited data exist, however, on their efficiency of operation.

6.10 Deep Well Injection

6.10.1 Introduction

Subsurface disposal may be injection into deep wells, placement in mined cavities, or injection in shales as a waste/grout mixture. It is emphasized that this is not a treatment method. The use of this method will result in irreversible pollution of a number of subsurface formations [29]. In addition, the representation of the method as final or permanent is unrealistic, since the injected waste may be subject to disposal by diffusion into natural subsurface flow systems.

Piper [30] considered that injection did not constitute permanent disposal. Although injecting liquid wastes deep beneath the land surface is a potential means for alleviating pollution of rivers and lakes, it is not a method that can encompass all wastes and resolve all effluent disposal problems. Piper considered that the physical, chemical, geologic, hydrologic, economic and institutional (including legal) limitations on injection were very stringent.

6.10.2 Formation evaluation

In view of these environmental concerns, great caution is required in the use of deep well injection.

Geological and hydrological conditions are the primary design considerations. An industry considering subsurface disposal must determine if an underground formation will accept fluids, at what rates

and pressure, and how the injected fluids will move within the formation. A suitable formation would have the following geological characteristics [31]:

- 1) uniform sandstone, limestone or dolomite or a fractured shale,
- 2) large areal extent,
- 3) sufficient thickness,
- 4) high porosities and permeabilities,
- 5) adequate overlying and underlying impermeable strata or aquicludes,
- 6) low pressure,
- 7) located well below and separated from fresh water horizon,
- 8) salt water filled and artesian in nature,
- 9) waters which are of no economic value either now or in the foreseeable future,
- 10) fluids and rocks which are compatible with the injected fluid, and
- 11) no unplugged wells that penetrate the formation in the vicinity of the disposal well.

Hydrological conditions are extremely complex and are one of the least understood variables for deep well injection. There are case histories of wastewater injection into apparently geologically suitable formations; however, no monitoring was practised to determine where and how the fluid was dispersing and what the long term effects were.

Intense hydrological investigation should be carried out including test boring and monitoring of groundwater movement.

6.10.3 Conclusions

In conclusion, the storage capacity of geological formations is limited and is reusable when used for gas or fresh water storage but not reusable for the disposal of wastes. This method of food industry wastewater disposal is not recommended unless a suitable alternative does not exist.

6.11 Summary of Process Design

6.11.1 Spray irrigation

Pretreatment requirements (for details see Section 6.4.1)

- 1) Usually coarse screening with stationary, vibrating or rotary screens.
- 2) pH adjustment (for wastewater pH should be between 6 and 9.5).
- 3) Deodorization (odour masking).
- 4) Biological pretreatment
 - a) domestic sewage treatment
 - b) pathogen removal.

Cover crop selection (for details see Section 6.4.2)

Function of the objectives:

- 1) Maximum water removal - sod crops and forests.
- 2) Nutrient removal - sod crops, row crops and grain crops.
- 3) Economic return - grain crops and row crops.

Loading rate determination (for details see Section 6.4.3)

1. Hydraulic loading rate

- a) $R_w = P + D/10$ (Equation (1)).
- b) $A_w = .01 Q/R_w$ (Equation (3)).
- c) P (Table 2).

2) Organic loading rate

- a) Table 14.
- b) Proper irrigation scheduling important.
- c) Pilot studies and/or laboratory column experiments.

3) Nutrient loading rate

- a) Figure 5.
- b) $A_n = N \cdot Q \cdot 10^{-3} / R_n$ (Equation (4)).
- c) $A_p = P \cdot Q \cdot 10^{-3} / R_p$ (Equation (5)).

4) Inorganic loading rate

Tables 5 and 8.

Selection of limiting loading rate (for details refer to Section 6.4.4)

Minimum of A_w , A_n and A_p .

Hydraulic application rates and irrigation schedules (for details refer to Section 6.4.5).

- 1) Wetting period - 10 to 12 hours.
- 2) Drying period - two days to six weeks.
- 3) Wetting period: drying period = 1:4.
- 4) $I = 0.01 W/TA_i$ (Equation (6))
- 5) $A_i = A/C_i$ (Equation (7))
- 6) T less than 10 or 12 hours.
- 7) C_i greater than four or five days.
- 8) Infiltration rate (I) shall be less than the values found acceptable through pilot studies.

Buffer zone requirements (for details refer to Section 6.4.6)

- 1) 15 to 60 metres around the site.
- 2) May be defined by provincial legislation.

Land forming requirements (for details refer to Section 6.4.7)

Usually minimal except for runoff diversion.

Underdrainage effluent collection (for details refer to Section 6.4.8)

- 1) Wells, buried drain lines, open drainage ditches.
- 2) Spacing controlled by permeability and depth of wetted material.
- 3) Pilot studies.

Storage requirements (for details refer to Section 6.4.9)

Winter Storage

- 1) $P = 100 P_T \cdot M \cdot A$ (Equation 6.8)
- 2) $S = P + W$ (Equation 6.9)

Summer Storage

- 1) Two-week wastewater storage basin.

Distribution system design (for details refer to Section 6.4.10)

- | | |
|---------------------------------|---------------------------------|
| 1) Transmission to Site | 2) Distribution to Outlets |
| a) pressure or gravity | a) fixed or moving systems |
| b) flow velocity - 2.5 to 3 m/s | b) above ground or buried |
| | c) design of mains and laterals |

- d) sprinkler spacing
- e) nozzle sizing
- f) valves
- g) pumps

- 3) Moving sprinkler systems.
- 4) Standby units.
- 5) Monitoring and metering equipment.

Monitoring requirements (for details refer to Section 6.4.11)

- 1) Renovated water
 - a) groundwater quality
 - b) groundwater level
 - c) groundwater movement.
- 2) Cover crops
 - objective - optimize growth and yield.
- 3) Soils
 - a) salinity
 - b) SAR
 - c) nutrients
 - d) boron
 - e) heavy metals
 - f) pH
 - g) CEC.

6.11.2 Flood irrigation

Pretreatment requirements

Similar to spray irrigation (Section 6.4.1).

Cover Crop Selection (for details refer to Section 6.5.2).

Sod crops most suitable (Section 6.4.2).

Loading rate determination (for details refer to Section 6.5.3).

- 1) Hydraulic loading rate
 - a) Similar to Spray Irrigation (Section 6.4.3a).
 - b) Depth of flooding - 5 to 7 cm.

2) Organic Loading Rate

- a) Drying period quite important.
- b) Use of pilot studies.

3) Nutrient Loading Rates

Similar to spray irrigation (Section 6.4.3c).

4) Inorganic Loading Rate

Similar to spray irrigation (Section 6.4.3d).

Selection of Limiting Loading Rate

Similar to Spray Irrigation (Section 6.4.4).

Hydraulic application rates and irrigation schedule (for details refer to Section 6.5.6)

- 1) Equations summarized under spray irrigation (Section 6.4.5).
- 2) Infiltration rate (I) greater than 8 and less than $18 \text{ m}^3/\text{hr}$ per metre width of land for clay.
- 3) Infiltration rate (I) greater than 45 and less than $63 \text{ m}^3/\text{hr}$ per metre width of land for sand.
- 4) C_i approximately 6 to 14 days.

Buffer zone requirements

Similar to spray irrigation (Section 6.4.6).

Land forming requirements (for details refer to Section 6.5.8)

- 1) Flooding basin strips of width 6 to 30 m and length 182 to 425 m.
- 2) Levees from 2 to 2.5 m wide at the base and 30 to 45 cm high.

Underdrainage effluent collection

Similar to spray irrigation (Section 6.4.8).

Storage requirements

Similar to spray irrigation (Section 6.4.9).

Distribution system design (for details refer to Section 6.5.11)

- 1) Transmission to site similar to spray irrigation (Section 6.4.10).
- 2) Flooding by means of concrete-lined ditches with slide gates or by gated aluminum pipe.

- 3) Not easily adapted to automatic control.

Monitoring requirements

Similar to spray irrigation (Section 6.4.11).

6.11.3 Ridge and furrow irrigation

Pretreatment requirements

Similar to spray irrigation (Section 6.4.1).

Cover crop selection (for details refer to Section 6.6.3)

- 1) Row crops most suitable.
- 2) May be adapted to small grains and sod crops.

Loading rate determination (for details refer to Section 6.6.4)

- 1) Hydraulic loading rate
Similar to spray irrigation (Section 6.4.3a).
- 2) Organic loading rate
 - a) Organic suspended solids concentration is critical.
 - b) Column experiments or pilot studies.
- 3) Nutrient loading rate
Similar to spray irrigation (Section 6.4.3c).
- 4) Inorganic loading rate
Similar to spray irrigation (Section 6.4.3d).

Selection of limiting loading rate

Similar to spray irrigation (Section 6.4.4).

Hydraulic application rates and irrigation schedules (for details refer to Section 6.6.6).

- 1) Similar to spray irrigation (Section 6.4.5).
- 2) Infiltration rate (I) determined through pilot studies.
- 3) C_i usually 6 to 14 days.

Buffer zone requirements

Similar to spray irrigation (Section 6.4.6).

Land forming requirements (for details refer to Section 6.6.8)

- 1) Furrow slopes of 0.5 to 3% preferable.
- 2) Spacing of furrows determined by cover crops.
- 3) Furrow depth - 20 to 30 cm for low permeability; 8 to 13 cm for highly permeable soils.
- 4) Furrow lengths - 90 to 200 metres.

Underdrainage effluent collection

Similar to spray irrigation (Section 6.4.8).

Storage requirements

Similar to spray irrigation (Section 6.4.9).

Distribution system design (for details refer to Section 6.6.11).

- 1) Transmission to site similar to spray irrigation (Section 6.4.10).
- 2) Flow distribution from earth supply ditches, concrete flumes or gated aluminum pipe.

Monitoring requirements

Similar to spray irrigation (Section 6.4.11).

6.11.4 Infiltration-percolation

Pretreatment requirements

Similar to spray irrigation (Section 6.4.1).

Cover crop selection (for details refer to Section 6.7.3)

- 1) Cover crop of minor importance.
- 2) Crop must be tolerant of wet conditions.
- 3) Use of pea gravel.

Loading rate determination (for details refer to Section 6.7.4)

1. Hydraulic loading rate

- a) Similar to spray irrigation (Section 6.4.3a).
- b) $R_w = P$
- c) Pilot studies important.

2. Organic loading rate

Organic suspended solids concentration critical.

3. Nutrient loading rate

Pilot studies important.

4. Inorganic loading rate

Similar to spray irrigation (Section 6.4.3d).

Selection of limiting loading rate

Similar to spray irrigation (Section 6.4.4).

Hydraulic application rates and irrigation schedules (for details refer to Section 6.7.6)

Similar to spray irrigation (Section 6.4.5).

- 1) Duration of the wetting period (T) usually greater than nine hours but less than two weeks.
- 2) Length of the irrigation cycle (C_i) usually greater than 24 hours but less than three weeks.

Buffer zone requirements

Similar to spray irrigation (Section 6.4.6).

Land forming requirements (for details refer to Section 6.7.8)

- 1) Construction of flooding basins.
- 2) Basin sizes range from 0.4 to 4 hectares or more.
- 3) Dike height of 1.2 metres is common.

Underdrainage effluent collection

Similar to spray irrigation (Section 6.4.8).

Storage requirements

Similar to spray irrigation (Section 6.4.9).

Distribution system design (for details refer to Section 6.7.11)

- 1) Transmission to site similar to spray irrigation.
- 2) Application techniques include riser pipe and high rate spray application.

Monitoring requirements (for details refer to Section 6.7.12)

- 1) Groundwater monitoring important - BOD_5 , suspended solids, nitrogen, phosphorus and total dissolved solids.

2) Basin surface condition.

6.11.5 Overland flow

Pretreatment requirements

Similar to spray irrigation (Section 6.4.1).

Cover crop selection (for details refer to Section 6.8.3)

Perennial sod crops such as Reed canary, rye grass and tall fescue most suitable.

Loading rate determination (for details refer to Section 6.8.4)

1) Hydraulic loading rate

Similar to spray irrigation (Section 6.4.3a).

a) $R_w = P + D/10 + S_R$ (Equation (10))

b) 40 to 80 percent of applied water appears as runoff.

c) Use of pilot studies.

2) Organic loading rate

Not well defined.

3) Nutrient loading rate

Need for post-treatment should be assessed through pilot studies.

4) Inorganic loading rate

Similar to spray irrigation (Section 6.4.3d).

Selection of limiting loading rate

Similar to spray irrigation (Section 6.4.4).

Hydraulic application rates and irrigation schedules (for details refer to Section 6.8.6)

Similar to spray irrigation.

Duration of the wetting period (T) commonly 6 to 8 hours.

Length of the irrigation cycle (C_i) commonly 16 to 18 hours.

Buffer zone requirements

Similar to spray irrigation (Section 6.4.6).

Land forming requirements (for details refer to Section 6.8.8)

1) Optimum slope - 2 to 8 percent.

- 2) Optimum slope length - 45 to 90 metres.
- 3) Slopes must be uniform in cross section and free from gullies.
- 4) Ditches required to intercept runoff.

Underdrainage effluent collection (for details refer to Section 6.8.9)
May be needed to lower the natural water table below the root zone.

Storage requirements (for details refer to section 6.8.10)
Similar to spray irrigation.

$$S = W + 100 \text{ PA (Equation (11))}$$

Distribution system design (for details refer to Section 6.8.11)

- 1) Spray application usually used (design similar to spray irrigation).
- 2) Surface application methods for low organic solids concentrations.
- 3) Runoff collection system - gravity - flow channels or closed pipe and pumps.

Monitoring requirements (for details refer to Section 6.8.12)

- 1) Wastewater application rates (m^3/day).
- 2) Runoff flow rate (m^3/day).
- 3) Wastewater quality.
- 4) Runoff water quality.

7 ECONOMIC ANALYSIS

7.1 Introduction

A cost analysis and comparison of alternatives must be carried out in order to select the best land application method for wastewater disposal. This analysis may be carried out in two stages. The first stage is a preliminary screening to determine those which are cost competitive. This stage is usually carried out early in the planning process and involves the review of alternatives on the basis of approximate cost estimates. The second stage of the economic analysis is based on the evaluation of preliminary designs and detailed costs. A discussion of the second stage now follows.

There are several steps in the cost analysis. It is necessary that each alternative must be clearly defined so that detailed cost estimates can be made and a schedule of expected disbursements and receipts estimated. Present worth or annual cost calculation techniques are used to compare alternatives. Prior to showing the development of the economic analysis, it is pertinent to define and discuss a number of terms:

1) Planning Period

The planning period is the time frame for which the waste treatment system is evaluated. The planning period commences with the initial operation of the system; the time period for waste treatment systems is generally 20 years.

2) Capital Costs

Capital costs include the following:

- a. all contractor's costs of construction including overhead and profit,
- b. costs of land, relocation of people, property and right-of-way, and ease of acquisition,
- c. design engineering, field exploration and engineering services during construction,
- d. administration and legal services,

- e. start-up costs such as operator training,
- f. interest charges during construction.

3) Annual Operating and Maintenance Costs

Annual operating and maintenance costs include such items as electrical power, labour, maintenance supplies and monitoring.

4) Negative Costs (Benefits)

Negative costs should be incorporated into the analysis. Revenue producing benefits (negative operating and maintenance costs) and salvage values (negative capital costs) are included in this category.

Possible sources of revenue from the operation of a land application system include the following:

Sale of cover crops. In general, the return from the sale of crops will only offset a portion of the total operation and maintenance costs, although it should cover the costs of planting, cultivation and harvesting.

Sale of treated wastewater. The sale of treated water is most applicable to overland flow and infiltration percolation systems. The return will depend on the economic value of water in the area and the restrictions placed on the use of treated water.

Sale of surplus effluent. The sale of surplus effluent is practiced at some land application sites and such a scheme may serve to reduce storage costs in addition to providing a source of revenue.

Lease of land. As an alternative to the company itself conducting farming operations, land may be leased to a local farmer with the lease agreement stipulating requirements for storing or applying effluent. Land used during the summer for agricultural operations may also be leased to individuals or groups at other times of year for recreational purposes, e.g. for duck hunting during the late fall.

Salvage values that should be considered in the cost analysis are the salvage values of land, structures and equipment that will be realized at the end of the planning period. Land for treatment works is assumed to have a salvage value equal to its prevailing market price at the time of analysis. Structures and equipment are assumed to have salvage value provided there is a use for them at the end of the planning period; the salvage value is estimated using appropriate depreciation methods. Salvage values may be claimed for equipment whose useful life is shorter than the planning period.

5) Land Acquisition or Control

There are several methods of land acquisition or control:

- a. purchase of land and direct control of the effluent application,
- b. leasing of land and direct control of the effluent application,
- c. purchase of land with lease back to farmer with lease clauses stipulating quantities of effluent to be applied,
- d. contract with a farmer stipulating quantities of effluent to be applied.

Each of these methods will require different treatment in the cost analysis. Purchase prices are capital costs and leasing or contractual arrangements involving annual operating costs or benefits. For the cost analysis, the prevailing market price of land should be determined from a reliable source.

6) Prices

The costs of the components of the alternative systems should be calculated on the basis of market prices prevailing at the time of the analysis. Inflation of wages and prices should not be considered (this approach implies that all prices involved will tend to change over time at approximately the same rate).

7) Present Worth and Annual Cost Calculations

The cost estimates for the different alternatives must be placed on a comparable basis by means of appropriate conversion techniques

that make use of compound interest factors. Either the present worth technique (whereby all expenditures and receipts over the planning period are reduced to a single figure) or the annual cost technique (giving a total amount cost which could include annual operation and maintenance costs plus amortized capital costs) may be used. The interest rate utilized in the calculations should be the minimum attractive rate of return appropriate in the particular investment circumstances of the firm involved.

These mathematical techniques are illustrated in a number of examples.

7.2 Cost Analysis

Following the preliminary design of waste treatment and disposal alternatives, estimates of capital and operating costs for each system should be determined. Local contractors and firms selling the equipment required should be contacted for estimates.

Proposed investments in industrial assets are considered attractive if it appears that the investment will be recovered with at least the minimum rate of return available given the individual firm's particular circumstances. The introduction of this requirement is reflected in interest rates used to calculate costs.

Each alternative will have a different series of monetary disbursements and receipts over a specified time frame. There are several methods for comparison of alternatives: two methods which are suggested are the annual cost approach, and the present worth approach. For illustrative purposes, a time frame of 20 years has been assumed (in concurrence with accepted practice in Canada and the U.S.). The rate of return (interest) is assumed to be 10%. Using these two factors (20 years, 10% interest), a number of mathematical factors have been derived for use in the annual cost and present worth approaches:

- 1) the capital recovery factor (CRF) which when multiplied by a present debt gives the uniform end-of-year payment necessary to repay the debt,

- 2) the present worth factor for a single payment or receipt (PWF') which, when multiplied by a future receipt or payment, yields the principal that with compounded interest will give that future payment,
- 3) the present worth factor for a uniform series of payments or receipts (PWF) which, when multiplied by an equal series of future payments or receipts, yields the principal that with compounded interest will give that series of payments.

Although values for these factors for the given time frame and interest rate are presented in the following examples, values for other time frames or interest rates can be obtained from either tables presented in mathematics, finance or engineering economy texts or from direct calculation using the following formulae:

$$CRF = i(1 + i)^n / (1 + i)^n - 1 \quad (1)$$

$$PWF' = 1 / (1 + i)^n \quad (2)$$

$$PWF = [(1 + i)^n - 1] / i(1 + i)^n \quad (3)$$

where i = interest rates, n = time frame (in years).

To illustrate the technique of cost analysis, a hypothetical example is used. A food-processing plant discharges an average of 4550 m³/day of effluent during seven months of the year and a lesser amount (a total of 160,000 m³) during the remaining five months (winter). Pretreatment consists of coarse solids and grit removal followed by biological treatment in an aerated lagoon. The lagoon effluent is sprayed on 71 hectares of land. During the winter months the 160,000 m³ is retained in a storage basin for irrigation during the summer months.

7.2.1 Annual cost approach

For this approach, operation and maintenance costs are estimated on an annual basis. Sample cost calculation sheets are used to illustrate the approach. Capital Costs (Table 16) are amortized (i.e., the capital is paid back in equal installments) over the 20 year time frame in order to arrive at an estimate on an annual basis. In the example shown, the non-land subtotal is amortized by multiplying it by

TABLE 16 EXAMPLE OF COST CALCULATIONS:
ANNUAL COST APPROACH - CAPITAL COST

Alternative No.	<u>1</u>	Average Flow	<u>4550</u> m ³ /day
Type of System	<u>Spray Irrigation</u>	Analysis Date	<u>April 1977</u>
Cost Component	Total Cost \$	Amortized Cost* \$/yr	
Preliminary Treatment (Solids Removal and Aerated Lagoon)	<u>183,000</u>		
Transmission (Force Main and Pumps)	<u>309,000</u>		
Storage 160,000 m ³	<u>199,000</u>		
Field Preparation Site Clearing	<u>62,000</u>		
Distribution Solid Set Spraying (Buried)	<u>219,000</u>		
Distribution Pumping	<u>93,000</u>		
Underdrainage	<u>58,000</u>		
Additional Costs			
Admin. & Lab. Facilities	<u>58,000</u>		
Monitoring Wells	<u>3,000</u>		
Service Roads & Fencing	<u>58,000</u>		
SUBTOTAL	<u>1,242,000</u>		
Engineering & Contingencies @ 30%	<u>372,000</u>		
SUBTOTAL	<u>1,614,000</u>	<u>189,600</u>	
Land @ \$2,470/ha	<u>176,000</u>	<u>17,600</u>	
SUBTOTAL	<u>1,790,000</u>	<u>207,200</u>	

* i = 10% n = 20 years CRF = 0.11746 PWF' = 0.1486

the capital recovery factor ($\$1,614,000 \times 0.11746$), resulting in an amortized cost of \$189,600 per year. A salvage value of zero at the end of the 20 year planning period is assumed for all components except land.

For land, the salvage value after 20 years is assumed to be the present marked value (\$176,000); the present worth (PWF') of this value is \$26,000 ($\$176,000 \times 0.1486$). The difference between the cost of the land and the present worth of the salvage value is \$150,000; this value is multiplied by the capital recovery factor of 0.11746 to obtain the amortized cost of land of \$17,600 (a similar procedure may be followed for any component with a salvage value).

These amortized capital costs are added to the annual operation and maintenance costs to arrive at a total annual cost for this alternative of \$278,300 (Tables 17 and 18).

7.2.2 Present worth approach

In this approach all costs throughout the planning period are reduced to their present worth. Capital and operating costs are calculated in the same way as in the annual cost approach (Tables 16 and 17); however, capital costs are not amortized. Rather, the annual operating and maintenance costs are brought to present worth by multiplying by the present worth factor (PWF) = $(\$71,100) \times (8.514) = \$605,300$. This present worth cost is added to the capital costs (assuming all capital costs are incurred at the start of the planning project) and the present worth (PWF') of the salvage value of land ($\$176,000 \times 0.1486 = \$26,000$) is subtracted, thereby giving a net present worth of net disbursements of \$2,369,000 (Table 19).

Both the present worth and annual cost methods will produce the same ranking of alternatives. Indeed, the present worth costs can be obtained from annual costs and vice versa. The present worth cost can be converted to an equivalent annual cost by multiplying it by the capital recovery factor (CRF). Alternately, multiplying each annual cost by the present worth factor (PWF) will give the present worth cost.

TABLE 17 EXAMPLE OF COST CALCULATIONS:
ANNUAL COST APPROACH OPERATION AND MAINTENANCE COSTS

	Annual Cost \$/yr			
	Labor	Power	Material	Total
Preliminary Treatment				
Solids Removal	<u>7,100</u>	<u>--</u>	<u>1,500</u>	<u>8,600</u>
Aerated Lagoon	<u>8,600</u>	<u>6,000</u>	<u>2,000</u>	<u>16,600</u>
Transmission				
Force Main	<u>--</u>	<u>--</u>	<u>500</u>	<u>500</u>
Effluent Pumping	<u>2,900</u>	<u>6,500</u>	<u>300</u>	<u>9,700</u>
Storage 160,000 m ³	<u>800</u>	<u>--</u>	<u>600</u>	<u>1,400</u>
Distribution				
Solid Set Spraying (Buried)	<u>12,300</u>	<u>--</u>	<u>1,500</u>	<u>13,800</u>
Distribution Pumping	<u>2,900</u>	<u>6,500</u>	<u>300</u>	<u>9,700</u>
Recovery				
Underdrains	<u>1,800</u>	<u>--</u>	<u>2,600</u>	<u>4,400</u>
Additional Costs				
Admin. & Lab. Facilities	<u>8,600</u>	<u>--</u>	<u>1,900</u>	<u>10,500</u>
Monitoring Wells	<u>500</u>	<u>--</u>	<u>100</u>	<u>600</u>
Service Roads & Fencing	<u>--</u>	<u>--</u>	<u>1,400</u>	<u>1,400</u>
Cultivation & Harvesting	<u>10,700</u>	<u>--</u>	<u>7,200</u>	<u>17,900</u>
Benefits				
Sale of Crop	<u>--</u>	<u>--</u>	<u>(24,000)</u>	<u>(24,000)</u>
SUBTOTAL	<u>56,200</u>	<u>19,000</u>	<u>(4,100)</u>	<u>71,100</u>

TABLE 18 TOTAL ANNUAL COST

Amortized Capital Costs	<u>\$207,200</u>
Operation & Maintenance Costs	<u>\$ 71,100</u>
<u>TOTAL ANNUAL COST</u>	<u><u>\$278,300</u></u>

TABLE 19 EXAMPLE OF COST CALCULATIONS:
PRESENT WORTH* APPROACH

Capital Costs	<u>\$1,790,000</u>
Present Worth (PWF) of Annual Costs	<u>\$ 605,300</u>
Present Worth of All Costs Paid Out	<u>\$2,395,300</u>
<u>LESS</u>	
Present Worth (PWF') of Salvage Value	<u>\$ 26,000</u>
Present Worth of Net Disbursement	<u><u>\$2,369,300</u></u>

* $i = 10\%$ $n = 20$ yrs $PWF = 8.514$ $PWF' = 0.1486$

8 SPECIFICATION OF CONSTRAINTS

8.1 Introduction

Following the design of a land application system and prior to implementation of the design, the proposed system should be re-evaluated with respect to particular constraints which will be imposed on it.

The purpose of this section is to discuss possible economic, operational and environmental constraints which must be assessed for each system.

8.2 Economic Constraints

Important factors which may impose financial constraints include pretreatment requirements, transmission of wastewater to the site and cost of available land.

Where pretreatment requirements are excessive (secondary biological treatment), it may be more economically advantageous to treat the wastewater by one of the aerobic processes summarized in Section 6.4.1(d) and then to discharge to a waterway if one of sufficient flow volume for dilution is conveniently located. Care must be taken in designing such a system to ensure that the effluent will meet Provincial and Federal effluent standards.

If suitable land for wastewater application is located a considerable distance from the processing plant, wastewater transmission costs may be substantial, especially for small plants. These costs include pumping stations, piping and costs of installation for the buried pipe.

Land costs are usually a significant component of the total land application system costs. Although present value of land does not usually depreciate over the amortization period, the cost of borrowing money for land purchase may be significant, especially for large plants. This cost should be compared with the land costs for other feasible land treatment alternatives as well as with the capital and operating costs of biological treatment.

8.3 Operational Constraints

Possible operational constraints associated with land application facilities have been discussed in Section 6. The following factors may limit the flexibility and/or efficiency of a land treatment alternative:

- 1) wastewater characteristics, especially suspended solids and inorganic minerals,
- 2) land slope,
- 3) soil infiltration rate and permeability,
- 4) soil depth,
- 5) depth to groundwater,
- 6) adverse geologic subsoil formations,
- 7) tolerance of the cover crop to excess loading of water and organic or inorganic wastewater constituents,
- 8) climatic constraints such as total amount and frequency of rainfall, duration and depth of snow cover, temperature distribution, and wind speed and direction.

Identification of each of the constraints is necessary to assess the feasibility of a selected alternative and to develop an operations manual.

8.4 Environmental Constraints

A number of environmental constraints which may be encountered in land treatment of food processing wastes are now discussed. Mitigative measures are briefly discussed within the context of the guidelines for preparation of environmental impact statements given in Appendix II.

8.4.1 Impact on the physical environment

a) Soil and vegetation. Adverse physical effects of land application on soils and vegetation may be caused by excessive concentrations of suspended solids, prolonged soil inundation, and presence of toxic compounds in the wastewater. Large concentrations of suspended solids may clog voids in the soil resulting in decreased infiltration and

percolation. Prolonged inundation of the soil with wastewater produces anaerobic conditions which alter chemical conditions and adversely affect plant growth. Wastewater high in TDS (total dissolved solids) may cause a salinity condition in the soil especially where annual evapotranspiration exceeds annual precipitation.

Organic compounds, such as phenols, surfactants and pesticides are usually not a problem in food industry wastes.

The effects of heavy metals and trace elements on plant growth are discussed in Section 2. Details of toxicity effects and acceptable levels of these elements are also presented in Section 2.

b) Groundwater. The groundwater quality and level may be affected by land application systems particularly in infiltration-percolation systems.

Nitrogen in nitrate form is of major concern in groundwater contamination. These aspects are discussed in Section 2. Other possible constituents of wastewater from food processing such as stable organics, dissolved salts, trace elements, and pathogens are discussed in Sections 2 and 5.

8.4.2 Impact on the biotic environment

a) Wildlife. Land application systems may affect certain indigenous terrestrial wildlife species.

Adverse effects due to lost habitat may be a result of land use changes due to clearing and site preparation. The value of the habitat must first be determined in assessing the degree of impact. However, for some animals the effects of reduced habitat may be nullified by the improved nutritive value of forage due to wastewater nutrients.

Wildlife may be also affected by contamination of forage and water supply by toxic substances and/or pathogens that may be present in the wastewater effluent. Untreated wastewaters from meat and poultry processing plants are a particularly significant source of pathogenic contaminants.

b) Fish and aquatic invertebrates. The impact on fish and aquatic invertebrates could be due to loss of habitat and reduced water quality.

The degree of impact on the quality and quantity of wastewater effluent reaching the water body. Although applied effluent should not be allowed to run off the site except in systems designed for surface runoff, serious environmental problems may result through inadequate design and/or mismanagement of the system.

These adverse effects may be due to reduced dissolved oxygen levels, pH changes, increases in suspended materials, toxicity of ammonia and adverse temperature changes.

Reduced dissolved oxygen in the streams may have serious effects on aquatic floral and faunal communities. A level of 4 mg/L is recommended by EPA Water Quality Criteria [32] as a minimum dissolved oxygen level for fish. However, this level is found to be low for some invertebrate species.

Altering the pH of receiving streams may be lethal to sensitive species of aquatic life or may inhibit their reproductive ability thus causing changes in the diversity of the aquatic community. As a result, only the more tolerant species would propagate.

To maintain a maximum level of protection of aquatic life, a pH range of 6.5 to 8.5 is recommended for stream water [32].

Changes in the pH may also augment toxicity levels of some pollutants in the stream. For example, it was reported that at lower pH levels some trace metals become more soluble and therefore may be more toxic to aquatic life [32].

Suspended solids reduce the penetration of sunlight to the trophogenic zone of a lake or stream causing a reduction in productivity of aquatic invertebrates. Thus the food availability may become a limiting factor in maintaining a viable fishery.

Fish visual requirements used for feeding and protection may become impaired by suspended solids. In addition, suspended matter may cause fish mortality by clogging of gill filaments and prevent successful development of fish eggs and larvae.

For a high degree of protection of fish and aquatic invertebrates it is recommended that the maximum level of suspended solids not exceed 25 mg/L [32].

Nitrogen transformations in wastewater were discussed in Section 3.2.5. Ammonia nitrogen, if allowed to enter a surface water, may be lethal to fish. The lethal concentration of ammonia is a function of pH. Ammonia at low pH levels is usually toxic only in large quantities, while at high pH levels, smaller amounts may be lethal. Water quality standards which utilize total ammonia generally restrict the total ammonia concentration in receiving waters to 2.0 mg/L at a pH of 8.0 or greater [33].

Degradation of aquatic habitats may result from changes in flow rates, rechanneling and siltation due to surface runoff.

Siltation of stream beds may result in reduced intergravel flow and reduced dissolved oxygen levels could exceed the tolerance levels of many benthic invertebrates. For example, the source of food for fish (stonefish, mayflies and caddis flies) may be replaced by more tolerant groups such as Diptera larvae and worms (Oligochaetae). Spawning sites of fish may also be destroyed by siltation.

c) Eutrophication. The natural eutrophication process occurring in water bodies may be greatly accelerated by enrichment from added nitrogen and phosphorus.

Wastewater from meat, poultry and dairy processing plants may contain high levels of nitrogen and phosphorus. Transformation mechanisms and nutrient effects in the soil and water environments are discussed in Sections 2 and 5.

During the winter months, aerobic decomposition of the algal biomass normally associated with eutrophic lakes may cause drastic reductions in dissolved oxygen levels. Oxygen levels below the minimum requirement of 4 mg/L could result in fish mortality.

Algal blooms are likely to develop in lakes during the summer when concentrations of inorganic nitrogen and inorganic phosphorus in the water are in excess of 0.2 - 0.3 mg/L and 0.01 - 0.02 mg/L, respectively, at the onset of the vegetative period [34].

8.4.3 Public health

Land application of food processing wastes is a potential source of disease [35]. No existing technology is capable of providing 100 percent removal of pathogens economically.

In evaluating the potential impact, special consideration is given to those effects relating directly to public health.

a) Groundwater quality. Jewell et al. [35] reported that the greatest threat posed by pathogenic organisms is groundwater contamination. The situation is particularly serious where wastewater is applied to land containing groundwater recharge areas. The potential hazard increases when the aquifer is near the surface and the recharge areas consist of coarse material.

The authors also indicated that the possibility of pathogen contamination associated with wastewater movement through the soil to the groundwater depends on the survival of pathogens in the soil. For example, helminth ova and protozoan cysts may become embedded in the soil and may remain viable for a long period of time. Groundwater contamination by pathogens is more commonly associated with meat processing wastes than with fruit and vegetable processing wastes.

Health problems associated with nitrates could result where wastewater from vegetable and meat processing plants are used in land application. Nitrates may enter groundwater by passing through the soil with the percolate. Nitrate in the diet may cause methemoglobinemia in infants.

b) Insects and rodents. Land application of wastes may result in ponding on the surface. Jewell et al. [35] reported that both the diversity and abundance of mosquitoes increased in areas where spray irrigation of wastewaters was practiced. A corresponding increase in avian blood parasites was also noted.

The propagation of mosquitoes and fly populations can be reduced by preventing unnecessary ponding of wastewater and providing sufficient drying periods between applications.

c) Runoff from site. Reports indicate that human Salmonella infections can be contracted from contaminated water used for recreation, drinking, food processing or from spray irrigation of vegetables and other food crops [36].

d) Aerosols. Aerosols are droplets of water from 0.01 to 50 microns in diameter which are created by releasing water under pressure. The aerosols are capable of carrying a viable pathogen through air currents. The most direct means of infection by pathogenic aerosols is by inhalation.

Aerosol travel and pathogenic survival depend mainly on wind, temperature, humidity and vegetative screens.

Safeguards that may be employed against aerosol transmission are as follows:

- Buffer zones around the field area.
- Sprinklers that spray laterally or downward with low nozzle pressure.
- Rows of trees and shrubs.
- Cessation of spraying operation during periods of high winds.
- Combinations of the enumerated measures with adequate disinfection.

e) Contamination of crops. Jewell et al. [35] reported that while a varying number of pathogens can be associated with food processing wastes, generally pathogens die off more quickly on vegetation than in the soil. The authors suggest that coliform bacteria may survive up to 35 days on vegetation, Salmonella typhi up to 68, and Tubercle bacilli up to 49 days on grass. Entamoeba histolytica cysts usually survive no longer than three days while Ascaris ova may live up to 35 days on vegetation.

A thorough study on the "Health Aspects of Sewage Effluent Irrigation" sponsored by the government of British Columbia, revealed 63 human disease outbreaks associated with the irrigation of soils and crops with untreated or poorly treated sewage in various countries throughout the world [36].

To minimize the threat to animals and human health from effluent irrigated crops, Jewell et al. [35] suggested the following:

- 1) vegetables irrigated by wastewater must not be eaten raw;
- 2) forage crops should be processed;
- 3) processed forage crops should be stored before feeding to livestock.

8.4.4 Impact on the social environment

The overall impact of the land application facility on land use and human habitat economics should be considered.

a) Land use. Site selection for the land application system should comply with regional land use plans. It is imperative that the current use, adjacent land use and proximity to areas developed for residential, commercial or recreational activities be ascertained.

b) Impact on residents. Irrigation and overland flow systems may require large tracts of land. The impact on local residents must be offset against any advantages of the proposed project.

c) Economics. The growth of a community may be stimulated or depressed by a land application facility. An evaluation of the impact on the local economy includes factors that are common to conventional systems. However, some additional factors may be applicable to land application system:

- 1) changes in site and adjacent land value,
- 2) removal of land from the tax revenue source,
- 3) possible changes to the quality of ground and surface waters that may result in additional treatment costs,
- 4) availability of an inexpensive source of water for irrigation.

9 SURVEY OF FOOD PROCESSING INDUSTRIES USING LAND DISPOSAL

9.1 Introduction

Part of the development of this manual included visits to and survey of 15 land application facilities in Canada and the United States. Available data on the conceptual and detailed design and operation of each system were gathered. The sites visited included fruit and vegetable processing plants, dairy plants, a turkey processing plant and an animal by-product processing plant. The information collected was useful in identifying problem areas for land disposal of food processing wastewaters.

Since all of the plants visited experience freezing temperatures and snow during the winter, useful information on winter operation of land application facilities was also obtained.

The results of the survey are described in order to clarify design and operational criteria to assess the applicability of the treatment processes used. A summary of this information has been provided in Appendix IV.

9.2 Fruit and Vegetable Processing Plants

9.2.1 Plant A

This is a vegetable processing plant canning a wide variety of vegetables during the summer and fall. A small amount of wastewater is produced during the winter months from the manufacture of non-seasonal products.

The wastewater from the canning operations consists of wash and flume water. Cooling water is discharged directly to the adjacent river. Wastewater flows may be as high as $6,800 \text{ m}^3/\text{day}$ (1.5 lmgd) during the peak of the canning season with a low-flow rate of $1,400 \text{ m}^3/\text{day}$ (0.3 lmgd). The cumulative yearly wastewater flow is $509,000 \text{ m}^3$ ($113 \times 10^6 \text{ gal}$). The organic strength of the effluent varies from 1,700 to 2,000 mg/L BOD_5 during peas processing to 3,800 to 4,100 mg/L BOD_5 during beets and corn processing.

Wastewater flows to a collection well and is pumped to a stationary sieve for removal of coarse solids. Since caustic peeling is used in the plant, the pH of the wastewater stream is continuously monitored and adjusted. Grit from the washing operations is removed by two sedimentation basins that are operated alternately to facilitate solids removal. The effluent collects in a wet well and is pumped approximately 2.5 km (1.5 miles) to the land application site to temporary storage in a 127 m³ (4,520 ft³) wet well before being pumped to the irrigation laterals by high pressure irrigation pumps. A storage lagoon has been constructed to store the wastewater generated during the winter months.

A sprinkler irrigation system is used to apply the wastewater to the land. Solid-set aluminum piping is used for the mains and laterals. Wastewater flow to the mains is controlled by valves located at the pumping station while flow to the laterals is controlled by hand-operated valves on each lateral. Laterals are spaced 37 metres (120 ft) apart and sprinklers, located on 0.3 metre (1 ft) risers are similarly spaced along the laterals.

A land area of 71 ha (175 acres) is used to dispose of the entire plant effluent from mid June to mid November. The soil is medium texture and the terrain is flat and level. Since groundwater depth is very shallow - 0.6 to 0.9 metres (2 to 3 ft) - a system of underdrains situated at a depth of 45 cm (18 in) is used to remove the treated effluent to a network of open drains from where it is pumped into the river.

A cover crop of Reed canary grass is irrigated with the wastewater. The crop is cut four or five times during the growing season and sold as fodder.

Two men are employed full time on the wastewater handling system during the spraying season. Their jobs consist of minor maintenance, line repairs and opening and closing valves. Operation of irrigation scheduling involves observation of field conditions during spraying and switching application sites before ponding occurs. Actual scheduling has proven to be quite variable and highly dependent on weather because of soil conditions at the site.

This land application system has been in operation for five years; initially problems were encountered with erosion of pipes and irrigation pumps. Following the installation of two sedimentation tanks this problem was eliminated.

Groundwater discharges are sampled regularly prior to discharge into the river to monitor concentrations of BOD_5 , suspended solids, nitrogen and phosphorus. The sodium adsorption ratio of the soil is also monitored regularly.

Capital and operating costs for this facility were not available.

9.2.2 Plant B

This plant processes peas, corn, lima beans, carrots and squash. Since processing occurs only during four months in summer and fall, land-disposal facilities are only used seasonally.

Wastewater effluent (flume and washwater and cooling water) is discharged to a sump and screened by a 40 micron rotary screen. The effluent is sprayed onto a very sandy (approximately 75%) soil which has a cover crop mixture of Reed canary, orchard and rye grasses. Wastewater flow rates vary from $0.6 \text{ m}^3/\text{min}$ to $2.2 \text{ m}^3/\text{min}$ (125 lpm to 475 lpm) with an average volume of approximately $1,475 \text{ m}^3$ (325,000 lgal) per day.

A spray irrigation system, similar to that at Plant A is used to apply the wastewater to 49 ha (120 acres) of land. An irrigation pump supplies wastewater at medium pressure (550 kN/m^2) to 96 spray nozzles located on low risers. Flow to the 10 cm diameter (4 in) laterals is controlled by four hydrants which are manually opened and closed.

The land application system at Plant B has been operating successfully for 20 years. During the initial years of operation, coarse solids were not removed from the effluent prior to irrigation and heavy caking on the soil surface was observed. The use of screening overcame this problem. Additional operational problems include erosion of pumps by sand, and periodic freezing in the pipes during cold weather if not drained after use.

During the spray season, one man is employed full time to operate the facility. The cover crop is mowed twice during the growing season; at the beginning and end of each season the land is disced thoroughly in order to break up any crust which may have accumulated on the surface.

Capital costs for this system were not available. Operational costs of the system are \$10,000 to \$12,000 per year including investment. The land, located adjacent to airport runways, is leased to the company by the city.

9.2.3 Plant C

This plant freeze packs peas, beans, corn, carrots, potatoes, pumpkins and squash. The plant operates 12 months a year with average daily flows of 270 m^3 (60,000 gal). Wastewater characteristics are dependent on the type of vegetable being processed. The total solids content of the irrigated wastewater varies from 2,000 to 7,500 mg/L and BOD_5 varies from 1,300 to 8,000 mg/L.

Wastewater pretreatment consists of coarse removal with rotary screens and pH adjustment of the potato processing wastewater. A spray irrigation system is used to apply the wastewater to a cover crop composed of native grasses. The 14 ha (35 acre) area used to treat the wastewater has a high clay content and as a result there is very little infiltration. During the late fall, when evapotranspiration rates are negligible, runoff rates are high. Runoff from the spray fields is collected in ditches and is treated in two aeration cells followed by a large aerobic polishing pond. Effluent from the polishing pond is periodically discharged to the adjacent creek. During the summer months, evapotranspiration rates are sufficient to utilize almost all the applied water.

During the winter, wastewater flows directly to the two mechanically aerated cells following solids removal. The treated effluent is stored for periods up to six months. The contents of the storage lagoon are used for irrigation during the warm summer months.

The grass is cut frequently to keep it short (less than 12 cm). The 4 ha site is spray irrigated on a four-day cycle. Rotation

consists of irrigation for four or five hours followed by a three day rest period. Since 1960 the only management problems associated with the system have been odours from the storage ponds during the spring. This problem was rectified by the addition of the aeration cells and partial aeration of the storage pond contents prior to irrigation.

Capital and operating cost information was not available.

9.2.4 Plant D

Plant D is a vegetable freezing plant similar to Plant C. It operates from June to the end of November, thus eliminating the need for winter storage facilities. Following coarse solids removal with a stationary screen, the daily flow of 270 m^3 (60,000 lgal) wastewater is applied to 55 ha (135 acres) of sandy soil with a spray irrigation system comprising 50 rain guns connected to portable mains. A three or four day irrigation schedule is used for wastewater application to a cover crop of native grasses. Each area is irrigated for seven or eight hours and then rested for two or three days.

9.2.5 Plant E

Plant E operates year round and processes fruits and vegetables for baby food. Plant effluent consists of washwater and wastes from fruit coring and fruit and vegetable pulping operations during two production shifts. Equipment is washed during the one clean-up shift each day and the washwater combined with the plant wastewater.

The 3,630 to $4,540 \text{ m}^3$ (670,000 to 840,000 lgal) daily wastewater flow are spray irrigated on 36 ha (90 acres) of fine sandy soil. Process wastewater leaving the plant flows via a 15 m^3 (2,770 lgal) sump through rotary screens to remove coarse solids. The wastewater flows to a 136 m^3 (25,000 lgal) sump for temporary storage prior to being pumped 5,490 m (18,000 ft) through a 25 cm (10 in) diameter concrete asbestos pipe to a field storage tank. It is then transported via a network of buried mains and laterals to spray guns located on 1.2 m (4 ft) risers.

Predesign activity prior to installation of this land application system consisted of determination of soil type and soil depth.

The soil is Ottawa fine sand on a clay bed located at a depth of 5.5 m (18 ft). The depth to watertable has been estimated to be 15 m (50 ft.).

The land application facility at Plant E is utilized year round. During the winter months there are alternating periods of freezing and thawing. Ice build-up of 0.6 to 0.9 m (2 to 3 ft) may occur around the sprinklers during short periods of time. An adjacent storage pond is used to collect runoff. Occasional freezing of sprinklers occurs in cold weather if the risers fail to drain properly.

The cover crop originally planted was Brome grass. It was formerly harvested for fodder but this practice was abandoned because it limited the land use flexibility for wastewater disposal. Currently, the grass is mowed frequently to keep it as short as several centimeters. Every second year a subsoiler is used to break up the surface and churn up the subsoil.

Irrigation scheduling is 12 hours of irrigation followed by a 3.5 day rest period. Operation of the schedule is left to the discretion of the operator who changes application sites before ponding occurs.

Several operational problems have been encountered during the 23 years of operation. Nozzles clog periodically with seeds and other large solids particles which bypass the screen. Frequent checking of the sprinkler heads has minimized this problem. Prior to introduction of buried iron and plastic piping, a portable system of aluminium piping was used. Grit caused gradual erosion of the aluminium while caustic used in the clean-up operation corroded the metal.

Current operation of the facility involves one full time operator on site and one part time operator at the solids removal facility at the plant. Current operating costs of the facility are \$110,000 per year including screening and disposal of screenings, irrigation equipment maintenance, and power and labour costs. Capital costs were not available.

9.2.6 Plant F

Plant F is a large potato dehydrating plant with a wastewater flow of $22 \times 10^4 \text{ m}^3/\text{day}$ (4.2 lmgd) made up of wash and process water from a dry caustic peeling process. The wastewater passes through fine screens and into a 30.5 cm (100 ft) diameter clarifier. During daylight hours, wastewater is piped directly to the fields, while at night the wastewater is stored in a lagoon having a three-day storage capacity. Due to concern over possible high sodium concentration in the wastewater, spills and leaks of caustic into the drain are minimized. The sodium adsorption ratio in the wastewater is maintained at 5.0.

Approximately 280 ha (700 acres) are used for wastewater irrigation, of which 32 ha (80 acres) are irrigated by sprinkler and the remainder utilizes a border dike system. Tail water from the dikes is collected in drains and pumped back to the head of the system. The soils in the area are somewhat variable but are primarily coarse textured. A mixture of Meadow Foxtail and Orchard grass is grown and harvested six times a year. The average yield is approximately 20 tonnes/ha (8 tons per acre).

Irrigation is carried out all year. Although temperatures may drop as low as -10°C , the irrigation water is quite warm, and wastewater freezing is not a problem. Reduced infiltration occurs in the early spring due to soil freezing. Over 250 cm (100 in) of wastewater is applied per year. The soil is underlain by fractured bedrock having very high permeability. The groundwater table stays below 3 metres (10 ft) from the surface. Each field is irrigated every six to eight days in the summer and less frequently in the winter. The wastewater is supplemented by irrigation water during the summer to maintain adequate soil moisture. One foreman and two labourers are employed full time on the project.

Prior to installation of the land application facility, wastewater treatment consisted of short detention ponds followed by discharge into a river. In order to assess land application to provide the required additional wastewater treatment, a pilot project utilizing 2 ha (5 acres) was started. The results obtained from these experiments were utilized in the design of the large scale project which has operated for four years.

Capital and operating cost information was not available.

9.2.7 Plant G

Plant G is a potato dehydrating plant. Annual flows of wastewater are approximately $2.7 \times 10^5 \text{ m}^3$ ($50 \times 10^6 \text{ lgal}$) made up of washwater and process water from the steam peeling process. Pretreatment consists of sedimentation for the washwater and clarification for the process water. The pretreated water is piped directly to the irrigation fields. Irrigation is carried out all year in spite of cold temperatures (-20°C). The temperature of the wastewater when it reaches the field is approximately 15°C .

Approximately 200 ha (500 acres) have been levelled and diked to form basins for flood irrigation. The present crop is a mixture of Reed canary grass and Timothy which is harvested twice a year for an annual yield of approximately 10 tonnes/ha (4 tons/acre). The fields are used for pasturing 200-300 head of cattle from late fall to spring. The soil is coarse textured and well drained. The rest periods between irrigations are 7 to 10 days during the summer and 25 to 50 days during the winter. Total annual application is approximately 160 cm (64 in) wastewater plus supplementary irrigation water during the summer. The facility utilizes one man to operate the primary treatment plant and one to operate the irrigation system.

Prior to installation of the land application system, the company had investigated three activated sludge treatment plants and concluded that this type of system was not satisfactory. A small pilot land application system was started several years ago. The results were used to establish application rates, organic loading, irrigation scheduling and best suited crops.

The operators analyze the wastewater daily and occasionally record water table levels. Groundwater quality is monitored regularly.

Capital and operating cost information was not available.

9.2.8 Plant H

Plant H is a vegetable processing plant packaging frozen peas, green beans, sweet corn, lima beans, carrots and potatoes in summer and

canning vegetables during the winter. Wastewater originates from washing and fluming operations. Average yearly wastewater flows are $595 \times 10^3 \text{ m}^3$ ($130 \times 10^6 \text{ lgal}$). Approximately $75 \times 10^3 \text{ m}^3$ ($17 \times 10^6 \text{ lgal}$) are generated during the winter months while the remainder is produced during the period May to November.

Wastewater is passed through 8 and 12 mesh shaker screens to remove coarse suspended solids. It flows 1,950 m (6,400 ft) by gravity through an underground 60 cm (24 in) diameter pipe to the land application site. A two stage primary sedimentation process at the site removes the grit and the effluent is spray irrigated.

The spray irrigation method utilized at Plant H is an example of an innovative method used to overcome inherent limitations in land application. The soil at the site is a heavy clay loam. As a result infiltration-percolation rates are extremely low. Initial percolation tests indicated that maximum allowable water application rates were 0.6 cm (0.25 in) per day or 6.0 cm (2.5 in) per week. Actual rates are approximately half this amount. This constraint combined with very hilly terrain increases the potential for runoff of applied wastewater rather than incorporation into the soil plant system. In addition, since the minimum depth to groundwater is only 60 cm (2 ft), the system is also constrained by the amount of wastewater which can be applied.

The spray irrigation system has been designed to maximize evapotranspiration rates. The system employs a series of atomizing nozzles (Figure 24) on top of 10 m (35 ft) towers (Figure 25). During warm weather, the evaporation losses resulting from dispersal of these minute water droplets have been estimated to be as high as 75 percent. Windspeeds of 16 km/hr (10 mph) or greater are required to disperse the water as it leaves the nozzles. The spray from these towers drifts as far as 0.4 km (0.25 miles) in the wind and very little water reaches the ground during hot summer weather. The atomizing nozzles were supplemented by a number of Rainbird No. 70 spray nozzles on 3.7 m (12 ft) risers. This system of conventional sprinklers is used during calm days when dispersal of the fog from the atomizing towers is inadequate.

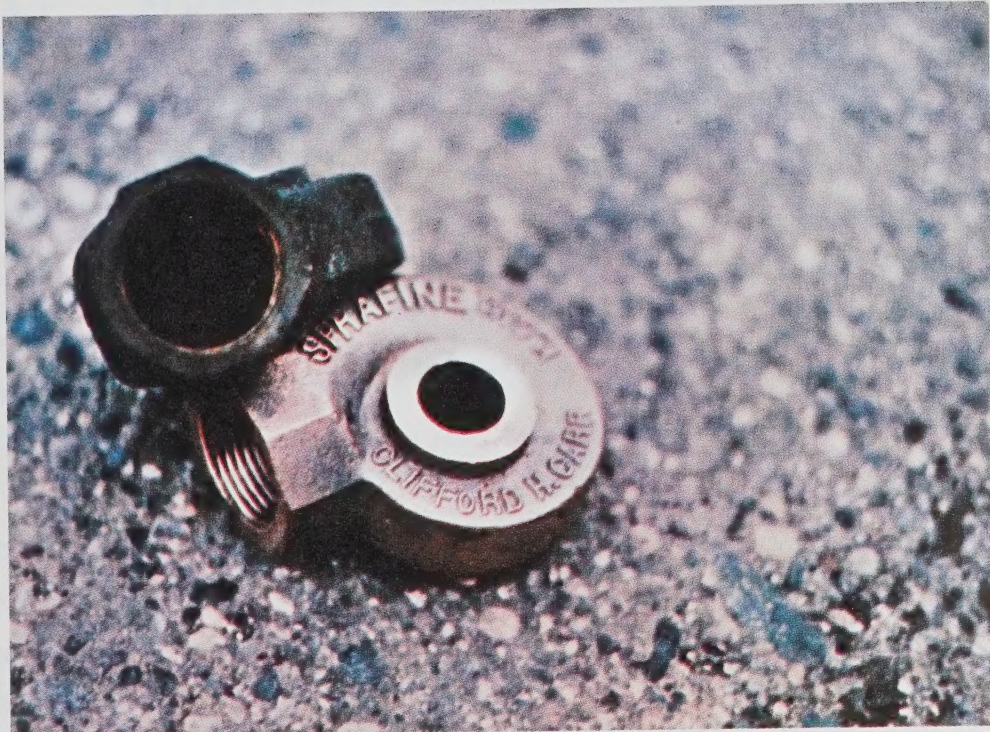


FIGURE 24. ATOMIZING NOZZLES (PLANT H).

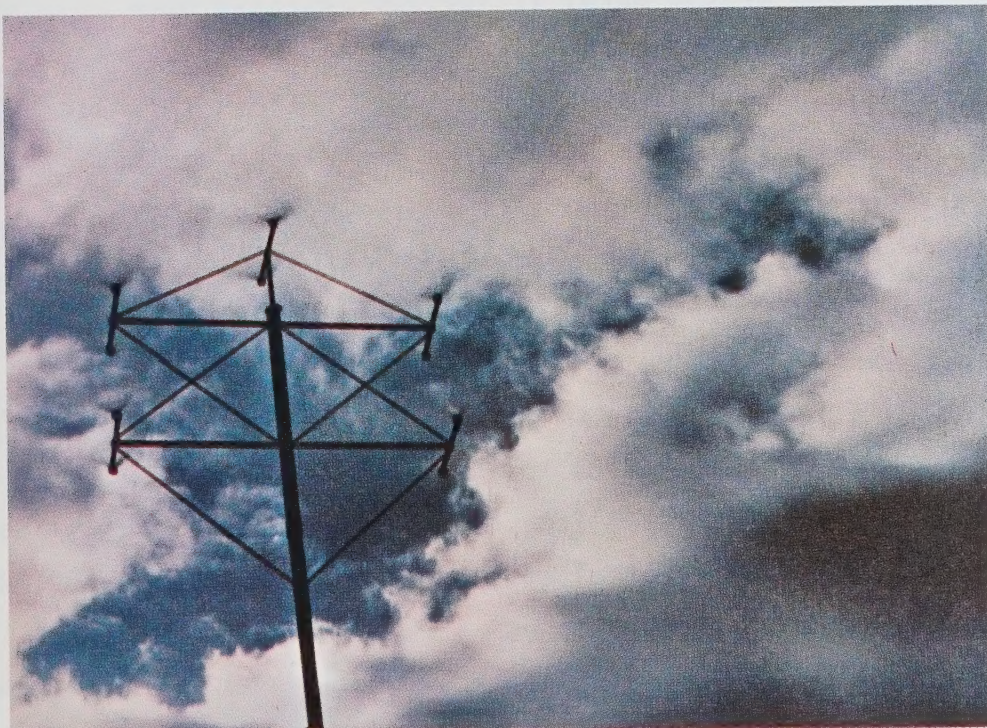


FIGURE 25. ATOMIZING TOWERS (PLANT H).

The entire volume of wastewater generated at the plant is disposed of on 180 ha (450 acres) of cropland during May to November. Various crops, grown in rotation, are utilized to recover some of the operational costs of the system. Brome grass, utilized because of its relatively high capacity for transpiration of water is grown and harvested for livestock fodder. It is rotated with other crops including a clover alfalfa mixture, field corn and peas. The income realized from these crops has reduced significantly the costs of the land application system.

The $7.5 \times 10^3 \text{ m}^3$ (16.7×10^6 gal) of wastewater generated during the winter months are stored in a lagoon at the land application site. During the late fall, the entire 8 km (5 miles) of portable aluminium piping used in the system is drained and dismantled.

The land application system was started in 1951. Plant personnel have been responsible for design of the present atomizing tower system. Developmental work has included experimentation with various atomizing nozzles and tower heights as well as with various sprinkler nozzles and riser heights to optimize the efficiency of water removal.

Operational problems of the spray irrigation facility have been experienced during cold-weather operation. Freezing temperatures periodically cause ice buildup on the spinkler nozzles. Unless this ice is regularly removed, complete freeze up of nozzles and risers occurs. In addition, the severe thermal contraction of the aluminium piping during cold weather has contributed to breakage of couplings.

Operational requirements of the facility primarily involve irrigation scheduling. Spray locations are switched every hour and the entire system operates on a 12 hour cycle. The flow to each lateral and tower is controlled by hand operated valves.

Net operational costs of the system including labour, electricity and depreciation, less the profit realized from the cover crop, are currently $3.5\text{¢}/\text{m}^3$ (12¢/1,000 gal).

9.3 Milk Product Plants

Several milk processing plants and one cheese plant utilizing land application of wastewater were also visited.

9.3.1 Plant I

Plant I is a milk processing plant producing condensed milk, milk powder, whey powder, and coffee cream. The 340 to 455 m³ (75,000 to 100,000 lgal) of wastewater discharged from the plant daily consists of floor and equipment washwater and sanitary sewage from the plant. Effluent leaving the plant is pumped first to 64 m³ (14,000 lgal) storage tank and then via a 1.6 km (1 mile) line to a 90 m³ (19,600 lgal) holding tank. The contents of the tank are aerated to prevent the formation of malodours during land application.

During the summer months, a sprinkler irrigation system disposes of the wastewater on 16 ha (40 acres). The soil is quite sandy and includes 10 cm (4 in) of topsoil. An irrigation schedule of approximately six days, consisting of one day of application followed by a five day resting period is being used. A solid set system consisting of 160 sprinkler nozzles spaced 24 m (80 ft) apart on laterals at 15 m (50 ft) between centres is used. Approximately 30 sprinklers are being used at any one time.

The cover crop consists of Reed canary, Timothy and Brome grasses. It is mowed at least once per week to maintain a height of not more than several centimeters high.

From December to March the wastewater is stored in a lagoon which is constantly aerated through diffusers on the floor of the lagoon. The contents of the lagoon are spray irrigated in the spring. Odour problems usually occur with the spraying of this stored effluent.

Capital and operating cost information was not available.

9.3.2 Plant J

Plant J produces butter, milk powder and concentrated milk all year round. Approximately 182 m³ (40,000 gal) of wastewater from washing milk tanks, floors and equipment is discharged from the plant daily.

During the summer, the effluent is coarse screened and pumped to a 27 m³ (6,000 lgal) holding tank prior to application by sprinkler irrigation to 16 ha (40 acres) of land. The presence of heavy clay in the low lying areas and sandy loam on the hills causes difficulty in irrigation scheduling.

A separate spray irrigation facility is used during the winter months. It utilizes sprinklers located in a 4 ha (10 acre) area with a natural surface drainage basin used to store the effluent in ice mounds. The runoff from these ice mounds, (up to 1.8 m (6 ft) thick) is collected in a storage lagoon at the bottom of the runoff basin and spray irrigated on the adjacent 16 ha (40 acres) of land in the spring. Odour problems have been minimized by floating the irrigation pump intake line and taking contents from the surface rather than the bottom of the lagoon.

A cover crop consisting of grasses native to the area (Couch and Brome grasses) is mowed regularly. Although the former practice consisted of sale of the cover crop for livestock feed, problems with scheduling of mowing occurred and in addition, heavy top growth prevented adequate drying of the topsoil thus resulting in odour.

Capital and operating cost information was not available.

9.3.3 Plant K

Plant K is a milk processing plant similar to Plants I and J. The $160 \text{ m}^3/\text{day}$ (35,000 lgpd) wastewater is disposed on 20 ha (50 acres) of grass cover crop on a heavy clay soil. A portable rain gun is used to spray irrigate the effluent. During December to April, wastewater is stored in a lagoon for subsequent irrigation during the summer months. The facility has been operating relatively trouble free for nine years.

Capital and operating cost information was not available.

9.3.4 Plant L

Plant L produces cheese in addition to butter, milk powder and concentrated milk. Approximately 95% of the 3,190 to 4,550 m^3 (580,000 to 830,000 lgal) effluent discharged daily consists of cooling water. The remainder is composed of washwater and whey.

The effluent flows by gravity through a 35 cm (14 in) diameter concrete asbestos pipe to the land application site located approximately 1.6 km (1 mile) from the plant. It is collected in a wet well and pumped to a 90 m^3 (16,700 lgal) clarifier to remove grit and large suspended solids. A spray irrigation system consisting of high capacity

rain guns ($81 \text{ m}^3/\text{hr}$ @ $1,035 \text{ kN/m}^2$) is used to apply the partially clarified effluent to 34 ha (85 acres) of grassland and forest. The subsoil at Plant L is coarse sand with a 10 cm (4 in) topsoil. Although soil percolation rates are quite high and depth to groundwater is 4.6 to 6 m (15 to 20 ft), runoff water collects at one end of the disposal site and forms a natural swamp (Figure 26) which attracts several hundred waterfowl each year.



FIGURE 26. USE OF SWAMPLAND FOR POLISHING AND STORAGE OF WASTEWATER (PLANT L)

During the summer months, an irrigation schedule of approximately 11 days (one day application followed by a 10 day resting period) is used to apply the effluent to 11 fields of Reed canary and Couch grass.

Although the facility has been expanded since its introduction in 1956, the initial field comprising a Reed canary grass cover has not

been mowed in 20 years. As a result, a loose mat of active and decaying vegetation approximately 30 cm (1 ft) thick has accumulated. Observation suggested that this mat might be beneficial in providing aeration and partial aerobic treatment of the wastewater as well as preventing compaction of the soil surface from the impact of water droplets. Plant personnel indicated that there have been no odour problems associated with this practice. Since the soil is very sandy, soil drying is greatly enhanced by high percolation rates, thus preventing anaerobic conditions at the soil surface.

A portion of the disposal area has been diked on all sides and is currently being used for disposal of effluent during January to March. Rain guns are used to spray irrigate the effluent during these three months of freezing temperatures. The sprayed effluent freezes and forms ice banks as high as 7.5 to 9 m (25 to 30 ft) around the rain guns.

Because of cover crop management practices, labour requirements at Plant L are minimal. Approximately four man-hours are required daily to check pumps, remove solids from the clarifier and to schedule irrigation.

Capital and operating cost information was not available.

9.3.5 Plant M

Plant M is a cheese processing plant which produces mozzarella cheese. The daily wastewater flow is approximately 7 m^3 (1,500 gal) and is applied to 0.8 há (2 acres) of grassland. During the summer, application by sprinkler irrigation is used and during the winter a system of broad irrigation is utilized to apply the wastewater.

The wastewater consists primarily of washwater from cheese processing. The whey is stored and processed separately. Wastewater effluent, which does not undergo any pretreatment prior to application, has a BOD_5 of approximately 1,000 mg/L.

During the summer, the wastewater is pumped via an above ground main to eight sprinkler nozzles. Application is scheduled so that only two sprinklers are being used at any time and every two days a

new pair of sprinklers is used. The cycle therefore consists of application for two days and resting for six days.

During the winter, freezing temperatures prevent operation of the sprinklers. The irrigation main is opened about halfway down the field and the effluent is pumped directly onto the field and removed by infiltration-percolation. Although the soil has a relatively high clay content, it has a low slope (approximately 5%) and there is sufficient land area to contain any runoff.

Capital and operating cost information was not available.

9.4 Meat Products

9.4.1 Plant N

Plant N is a turkey processing plant which utilizes a modified ridge and furrow method for effluent treatment. Approximately 454 m^3 (100,000 gal) of wastewater, composed mainly of washwater from processing operations is produced in the plant daily.

Offal and feathers are separated from the liquid wastes which are pumped approximately 0.8 km (0.5 miles) to an unused shallow gravel pit which acts as a small settling pond. It overflows into a ditch which is connected to lateral trenches 1.2 m (4 ft) wide by 1.2 m deep by 274 m (900 ft) long. Each trench is filled and the wastewater is allowed to infiltrate and percolate into the soil before it is filled with another batch of effluent. The system is illustrated in Figures 27 and 28. The total land area available for application is 3.2 ha (8 acres).

The soil at Plant N is quite sandy and is situated on a gravel bed which is located a few feet below the surface. Despite high soil permeability, the capacity of the system is limited by clogging of the bottom and sides of the trenches. To alleviate the problem, trenches are periodically cleaned with a backhoe and once clogging becomes too severe, they are filled in and new ones are excavated.

Capital and operating cost information was not available.

9.4.2 Plant O

Plant O is a rendering plant which collects blood, offal and feathers, and processes it to produce protein concentrate for animal



FIGURE 27. DISTRIBUTION DITCH FOR TURKEY PROCESSING PLANT EFFLUENT (PLANT N).



FIGURE 28. USE OF TRENCHES FOR WASTEWATER REMOVAL TO CROPLAND (PLANT N).

feeds. Wastewater consists of washwater, condensate from the cooling tower and storm drainage from the yard.

The wastewater undergoes primary and secondary treatment prior to land application by spray irrigation. Large suspended solids are removed by a sieve and microstrainer and the effluent passes through primary and secondary sedimentation tanks equipped with grease skimmers. Aerated lagoons provide secondary treatment prior to storage in two aerobic storage ponds.

The effluent from these storage ponds is applied to 70 ha (175 acres) of land with a sprinkler irrigation system using aluminum mains and laterals. Approximately $0.3 \times 10^6 \text{ m}^3$ ($60 \times 10^6 \text{ lgal}$) effluent must be disposed of annually during the six month frost free period. During the winter months, the effluent from the aerated lagoons is stored in the ponds. Effluent from the ponds has a BOD_5 of approximately 125 mg/L and a total solids concentration of approximately 100 mg/L.

Reed canary grass is used as a cover crop. The grass is cut about four times per season by a local farmer who uses it for livestock forage.

Since the initial start-up of the plant five years ago, several changes have been made to the wastewater handling system. Wastewater effluent was initially applied directly to the land without pre-treatment. Severe problems were encountered with clogging of the spray nozzles by large solid particles and the grass was killed by the high concentration of grease and oil. As a result, the primary and secondary wastewater treatment facilities were added. The initial method of wastewater application consisted of self-propelled rain guns. These were abandoned because of high labour requirements and replaced with the present solid set system.

Capital and operating cost information was not available.

9.5 Conclusions

Each of the food processing plants visited was under similar environmental constraints. They were situated in relatively small towns whose municipal waste treatment facilities were unable to handle the large wastewater loadings characteristic of such plants. The proximity

to residential development has prevented the use of lagoons to provide some form of pretreatment because of odours. In addition, the operation of many of the fruit and vegetable processing plants was seasonal and secondary wastewater treatment facilities become difficult to operate.

Most of these plants, however, had relatively inexpensive land area available at reasonable cost. In addition, the land purchased for application of the wastewater provided a financial asset to the facility in all cases since land values have appreciated with time, and long term application of organic waste increases the fertility of the agricultural land utilized at these plants. These factors combined with the ability of land treatment systems to handle shock loadings and variable loadings have demonstrated the ability of land treatment systems to provide effective treatment of food processing wastewaters.

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APPENDIX I

GLOSSARY OF TECHNICAL TERMS

APPENDIX I

GLOSSARY OF TECHNICAL TERMS

Activated sludge process - A waste treatment process which uses micro-organisms in suspension to oxidize soluble and colloidal organic matter to CO_2 and H_2O in the presence of molecular oxygen.

Adsorption - A process in which soluble substances are attracted to and held at the surface of soil particles.

Aerobic - The presence of an abundant supply of molecular oxygen.

Ammonia - The first form of nitrogen which is formed following the hydrolytic breakdown of organic nitrogen.

Anaerobic - The absence of an abundant supply of molecular oxygen.

Annual cost technique - A method of economic analysis in which amortized capital costs are added to the annual operation and maintenance costs to arrive at a total annual cost.

Available water capacity - The amount of water retained by a soil between the field capacity and the wilting point.

Five-day biochemical oxygen demand (BOD_5) - A measurement of the oxygen utilized in the stabilization of the organic matter in wastewater by microorganisms over a five day period at 20°C .

Cation exchange capacity - A measure of the ability of a soil to retain positively charged ions.

Chemical oxygen demand (COD) - A measurement of the total content of organic matter as determined by chemical oxidation of the wastewater.

Deep-well injection - The pressurized discharge of wastewaters underground into deep wells or mines sometimes hundreds of feet deep or into subsurface shale formations. Additional geological characteristics are discussed in Section 6.10.

Denitrification - The microbial reduction of nitrite and nitrate with the liberation of molecular nitrogen or nitrous oxide.

Electrical conductivity - A measurement of soil salinity and usually expressed as mmhos/cm.

Enteric bacteria - Those bacteria which grow in the intestinal tract and are thus an indicator of faecal contamination.

Eutrophication - The enrichment of a body of water with plant growth nutrients.

Evapotranspiration - The unit amount of water used on a given area in transpiration, building of plant tissue and evaporation in any specified time.

Field capacity - That moisture content of the soil when gravitational water has been removed. Gravitational water is that part in excess of hygroscopic and capillary water which will move out of the soil if favourable drainage is provided.

Groundwater table - The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Hydraulic loading rate - The rate at which water is applied to the soil.

Infiltration rate - The rate of entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation - An approach to land application in which wastewater hydraulic loading rates are relatively high; the water infiltrates the surface and percolates through the soil pores.

Inorganic loading rate - The rate of application of wastewater constituents such as heavy and light metal ions.

Irrigation - Application of water to the land to meet the growth needs of plants.

Lysimeter - A tank placed in the ground filled with soil natural to the surroundings and seeded with the same vegetation as the surroundings. Weighing of the tank and contents is used to determine consumptive water use.

Mineralization - The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Nitrification - The biological formation of nitrite and nitrate from compounds containing reduced nitrogen.

Nutrient loading rate - The rate at which the major plant nutrients, nitrogen and phosphorous, are applied to the soil.

Organic loading rate - The rate at which organic material, expressed as BOD or COD, is added to the soil.

Overland flow - Wastewater treatment by spray-runoff; wastewater is sprayed onto gently sloping, relatively impermeable soil that has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms - Microorganisms that can transmit diseases.

Percolation - The movement of water beneath the ground surface both vertically and horizontally, but above the groundwater table.

Permeability - The ability of a soil to allow appreciable movement of water through it when saturated and actuated by hydrostatic pressure.

pH - A term used to express the intensity of the acid or alkaline condition of a solution.

Piezometer - An instrument used to measure the pressure of water in the soil.

Potential evapotranspiration - The maximum quantity of water capable of being lost as water vapour in a given climate, by a continuous stretch of vegetation covering the whole ground and kept adequately watered.

Present worth technique - A method of economic analysis in which annual operating and maintenance costs are multiplied by a present worth factor and added to the capital costs to get a present worth value.

Regolith - The layer of disintegrated and decomposed rock fragments, including soil, just above the solid rock of the earth's crust.

Ridge and furrow irrigation - the surface application of water to the land through formed furrows; wastewater flows down the furrows and plants may be grown on the ridges.

Rotating biological contactor - A secondary biological wastewater treatment system which consists of large diameter plastic media discs mounted on a horizontal shaft and placed in a concrete tank. The discs which have a film of attached microorganisms are rotated through the

wastewater in the tank; in so doing they pick up a film of wastewater. As the discs are rotated back out of the tank this film trickles down over the attached film of microorganisms on the drum and oxygen enters the combined layer of wastewater and microbial mass.

Saline soil - A nonalkali soil containing sufficient soluble salts to impair the productivity.

Screening - The removal of coarse suspended solids from wastewater by mechanical filtering.

Sodium adsorption ratio - A mathematical relationship used to describe the ratio of sodium to calcium and magnesium.

Soil structure - The organization of individual soil particles into clumps or aggregates.

Soil texture - The relative proportions of the various soil separates - sand, silt and clay.

Spray irrigation - The application of the effluent above the ground surface by a sprinkler system in a manner similar to rainfall.

Substrate - That portion of the wastewater which is acted upon by microbial enzymes.

Subsurface leaching - The use of tile fields and leaching pits to remove partially treated wastewater through the subsoil. Renovation of the wastewater is achieved with the aid of soil microorganisms.

Suspended solids - Mineral and organic matter which has not been dissolved in the wastewater solution and which can be mechanically filtered.

Topography - The relief features or surface configuration of a land area.

Total dissolved solids - That portion of mineral and organic matter that has entered the wastewater solution and which cannot be removed mechanically by filtration.

Transpiration - The net quantity of water absorbed through plant roots that is used directly in building plant tissue, or given off at the atmosphere.

Trickling filter - An aerobic wastewater treatment process which consists of a bed of highly permeable media to which microorganisms are attached and through which the wastewater is percolated.

Volatilization - The process of evaporating or passing off as a gas.

Wilting point - The soil moisture content when plants permanently wilt. A plant is considered to be permanently wilted when it will not recover after being placed in a saturated atmosphere.

APPENDIX II

CLIMATOLOGICAL PUBLICATIONS AVAILABLE FROM
ATMOSPHERIC ENVIRONMENT SERVICE, FISHERIES AND ENVIRONMENT CANADA

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CLIMATOLOGICAL PUBLICATIONS AVAILABLE FROM
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CANADIAN NORMAL TEMPERATURE 1941-1970 Volume 1-SI

This volume provides normal values of temperature in Celsius for all regions in Canada based on the period 1941-1970. Included are tables for mean daily temperature, mean daily maximum temperature, mean daily minimum temperature, extreme maximum temperature, extreme minimum temperature and number of days with frost.

CANADIAN NORMAL PRECIPITATION 1941-1970 Volume 2-SI

This volume provides normal values of rain and precipitation in millimetres and snowfall in centimetres for all regions in Canada based on the period 1941-1970. Included are tables for mean rainfall, mean snowfall, mean total precipitation, greatest rainfall in 24 hours, greatest snowfall in 24 hours, greatest precipitation in 24 hours, number of days with measurable rainfall, number of days with measurable snowfall, number of days with measurable precipitation.

CANADIAN NORMALS - Volume 3 Wind 1955-1972

This volume provides tables for percentage frequency of winds and average wind speed in miles per hour, 8 and 16 compass points and computed annual maximum wind speeds with 10, 30, 50 and 100 year return periods (mph).

FROST DATA 1941-1970 by G.M. Hemmerick and G.R. Kendall

Tables show the co-ordinates and elevation of each station from which the data have been taken, the average date of the last spring frost and

the first fall frost and the duration of the growing season. Extremes of frost are also listed in the tables. Values are given for the earliest and latest extreme frost dates along with the longest and shortest frost-free seasons.

SHORT DURATION RAINFALL STATISTICS prepared by Headquarters Hydrometeorological Services Section

This book contains graphs of extreme rainfall statistics for about 100 stations across Canada plus an explanation of how these graphs were computed.

GROWING DEGREE - DAY NORMAL ABOVE 42°F - Based on the Period 1953-1967 by D. Aston

This publication contains data of normal growing degree days based on daily observations at 150 principal observing stations in the country over the 15 years of record from 1953-1967. One growing degree day results for each degree that the mean temperature for the day is above 5°C. No degree days are counted when the mean temperature is below 5°C.

Additional pertinent climatological data available from the Atmospheric Environment Service include the following:

- 1) THE CLIMATE OF CANADA - by C.C. Boughner and M.K. Thomas.
This 74 page booklet contains a detailed discussion of the provincial and territorial climates of Canada, an introduction on climatic controls and climatic regions, four maps, a list of references and source material and climatic tables from 45 stations.
- 2) ATLAS OF CLIMATIC MAPS
A spirally bound atlas containing 10 series of climatic maps of Canada; Series 1 - Temperature; 2 - Precipitation; 3 - Pressure; 4 - Bright Sunshine; 5 - Cloud Amount; 6 - Radiation; 7 - Vapour

Pressure; 8 - Evaporation; 9 - Mean Daily Minimum Temperature; 10 - Mean Daily Maximum Temperature. Published in 1971.

- 3) ATLAS OF RAINFALL INTENSITY - DURATION - FREQUENCY DATA FOR CANADA - by J.P. Bruce.

Climatological Studies Number 8. Rainfall maps are shown for various durations, return periods and ratios. Published in 1968.

- 4) SOIL TEMPERATURE DATA 1958-1972 - by D. Aston.

Lists average values at various depths (cm). The data are based on early morning and late afternoon readings. Replaces CDS #5-69. Published in 1973.

- 5) SNOW COVER - by J.G. Potter.

Climatological Studies Number 3. This 69 page book contains a description, tabular data, maps and frequency diagrams of the duration and depth of snow cover based on 20 winters. Published in 1966.

APPENDIX III

GUIDELINES FOR THE PREPARATION OF
ENVIRONMENTAL IMPACT STATEMENT

APPENDIX III

GUIDELINES FOR THE PREPARATION OF ENVIRONMENTAL IMPACT STATEMENT

Introduction

The purpose of an environmental impact assessment is to inform any decision making bodies of the anticipated biological and nonbiological effects of a project, to estimate the magnitude of the impact and to suggest possible mitigative measures.

Some of the conclusions reached in carrying out an environmental impact analysis are subjective due to lack of data and difficulty in quantifying some environmental parameters or effects.

The following questions should be addressed in an environmental impact study. Does it:

- 1) conflict with the environmental goals, objectives, plans, standards, criteria or guidelines adopted by the Province or the community where the project is to be located?
- 2) have an effect on any unique, rare or endangered species, habitat or physical feature of the environment?
- 3) have effects on an area of four hectares or greater?
- 4) have effects on adjacent persons or property or persons or property not associated with the undertaking?
- 5) necessitate the irreversible commitment of any significant amount of non-renewable resources?
- 6) pre-empt the use, or potential use, of a significant natural resource for any other purpose?
- 7) result in a substantial detrimental effect on air or water quality or on ambient noise levels for adjoining areas?

- 8) cause substantial interference with the movement of any resident or migratory fish or wildlife species?
- 9) establish a precedent or involve a new technology, either of which is likely to have significant environmental effects now or in the future?
- 10) act as a pre-condition to the implementation of another undertaking?
- 11) generate secondary effects (eg. land development, population growth) likely to significantly affect the environment?
- 12) block the views or adversely affect the aesthetic image of the surrounding area?
- 13) substantially change the social structure or demographic characteristics of the surrounding neighbourhood or community?
- 14) adversely affect human health?
- 15) overtax existing community services or facilities (eg. transportation, water supply, sanitary and storm sewers, solid waste disposal systems, schools, parks, health care facilities)?
- 16) create public controversy?

The following guidelines should provide the basis for the development of an environmental impact statement if possible.

Guidelines

Part A A statement addressing the proposed development.

1. The objectives of the project.
2. The project design plans.
3. The location of the project.

Part B The environmental setting - an inventory of:

1. The physical environment
 - a) climate
 - b) physiography
 - c) surfacial geology and soils
 - d) groundwater
 - e) watershed hydrology

2. The biotic environment

1) Wildlife

- a) habitats
- b) ungulates
- c) furbearers
- d) birds
- e) amphibians, reptiles and insects

2) Fish

- a) aquatic habitats
- b) water quality
- c) benthic invertebrates
- d) fish

3) Public health

- Disease

- a) groundwater quality
- b) insects and rodents
- c) aerosols
- d) contamination of crops
- e) mammals

3. The social environment

- a) history
- b) land use
- c) recreation
- d) demography and economics
- e) archaeology

Part C Environmental Impact Assessment

- 1. Impact on the Physical Environment
- 2. Impact on the Biotic Environment
- 3. Impact on the Social Environment
- 4. Suggested Mitigative Measures
- 5. Unavoidable Impacts.

APPENDIX IV

SUMMARY OF LAND APPLICATION DATA - SITE VISITS

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SUMMARY OF LAND APPLICATION DATA - SITE VISITS

Plant A

Products	Vegetable processing during the summer and fall; non-seasonal products during the winter.
Years of Operation	Five.
Wastewater Flows	1,400 to 6,800 m ³ /day; 509,000 m ³ /yr.
Land Area	71 hectares.
Wastewater Pretreatment	Stationary sieve, pH adjustment, grit removal.
Soil Characteristics groundwater (type, land area)	Medium texture; level terrain. Shallow depth.
Cover Crop (type, management)	Reed canary; cut and sold as fodder.
Storage	Winter storage lagoon.
Application System	Solid set, above ground sprinkler irrigation with underdrain effluent collection.
Operational Problems	Pipe and pump erosion prior to installation of grit tanks.

Plant B

Products	Canning peas, corn, lima beans, carrots and squash.
Years of Operation	20
Wastewater Flows	1,475 m ³ /day for four months.
Land Area	30 hectares.
Wastewater Pretreatment	40 micron rotary screen, deodorization (when required).
Soil Characteristics (type, land area)	Sandy (approximately 75%).
Cover Crop (type, management)	Mixture of Reed canary, orchard and rye grasses. Mowed twice per season. Soil surface disced at the beginning and end of each season.
Storage	None - seasonal operation.
Application System	Solid set above ground sprinkler irrigation.
Operational Problems	Solids caking prior to introduction of screens. Pump erosion. Pipe freezing.

Plant C

Products	Freeze packed peas, beans, corn, carrots, potatoes, pumpkins and squash.
Years of Operation	16
Wastewater Flows	270 m ³ /day for 12 months.
Land Area	14 hectares.
Wastewater Pretreatment	Rotary screens, pH adjustment. Aeration during winter and subsequent storage.
Soil Characteristics (type, land area)	Clay.
Cover Crop (type, management)	Native grasses. Frequent mowing to maintain grass below 12 cm.
Storage	Aerated lagoons and winter storage lagoon.
Application System	Solid set above ground sprinkler irrigation with runoff collection and polishing.
Operational Problems	Odour in spring prior to installation of aeration cells.

Plant D

Products	Freeze packed peas, beans, corn, carrots, potatoes, pumpkins and squash.
Wastewater Flows	270 m ³ /day (June to November).
Land Area	54 hectares.
Wastewater Pretreatment	Stationary screen.
Soil Characteristics (type, land area)	Sandy.
Cover Crop (type, management)	Native grasses. Frequent cutting.
Storage	None - seasonal wastewater production.
Application System	Sprinkler irrigation with rain guns.
Operational Problems	No significant problems.

Plant E

Products	Fruit and vegetable baby foods.
Years of Operation	23
Wastewater Flows	3630 to 4,540 m ³ /day (year round).
Land Area	36 hectares.
Wastewater Pretreatment	Rotary screens.
Soil Characteristics (type, land area)	Ottawa fine sand on a clay bed at 5.5 m. Depth to groundwater - 15 m.
Cover Crop (type, management)	Brome grass. Frequent mowing. Use of subsoil every second year.
Storage	Runoff storage pond.
Application System	Solid set buried sprinkler irrigation.
Operational Problems	Freezing of sprinklers. Clogging of sprinkler with solids. Pipe erosion (prior to use of iron and plastic pipe materials).

Plant F

Products	Dehydrated potatoes.
Years of Operation	Four.
Wastewater Flows	$22 \times 10^3 \text{ m}^3/\text{day}$ (year round).
Land Area	280 hectares.
Wastewater Pretreatment	Screening and sedimentation.
Soil Characteristics (type, land area)	Primarily coarse-textured underlain by fractured bedrock.
Cover Crop (type, management)	Mixture of Meadow Foxtail and Orchard grass. Harvested.
Storage	Lagoon for night storage.
Application System	Combination of sprinkler irrigation and border-dyke.
Operational Problems	No significant problems.

Plant G

Products	Dehydrated potatoes.
Wastewater Flows	$2.7 \times 10^5 \text{ m}^3/\text{yr}$ (year round).
Land Area	200 hectares.
Wastewater Pretreatment	Sedimentation.
Soil Characteristics (type, land area)	Coarse-textured.
Cover Crop (type, management)	Mixture of Reed canary and Timothy. Harvested twice annually.
Storage	None.
Application System	Flood irrigation.
Operational Problems	No significant problems.

Plant H

Products	Freeze packed peas, snap beans, sweet corn, lima beans, carrots, potatoes in summer. Canned vegetables in winter.
Years of Operation	25
Wastewater Flows	$595 \times 10^3 \text{ m}^3/\text{yr}$ (year round).
Land Area	180 hectares.
Wastewater Pretreatment	Shaker screens (8 and 12 mesh). Sedimentation.
Soil Characteristics (type, land area)	Clay loam. Hilly terrain. Minimum depth to groundwater - 60 cm.
Cover Crop (type, management)	Rotation crops including Brome grass, clover-alfalfa mixture, corn and peas. All crops harvested.
Storage	Winter storage lagoon (December to April).
Application System	Solid set above ground sprinkler irrigation using spray nozzles and fog nozzles.
Operational Problems	Nozzle freezing. Severe thermal contraction.

Plant I

Products	Condensed milk, milk powder, whey powder, and coffee cream.
Wastewater Flows	340 to 455 m ³ /day (year round).
Land Area	16 hectares.
Wastewater Pretreatment	Aeration.
Soil Characteristics (type, land area)	Sand with 10 cm sand-loam topsoil.
Cover Crop (type, management)	Mixture of Reed canary, Timothy and Brome grass. Mowed weekly.
Storage	Winter storage in aerated lagoon.
Application System	Solid set above ground sprinkler irrigation.
Operational Problems	Odour of stored effluent.

Plant J

Products	Butter, milk powder and concentrated milk.
Wastewater Flows	182 m ³ /day (year round).
Land Area	16 hectares.
Wastewater Pretreatment	Coarse screening.
Soil Characteristics (type, land area)	Mixture of heavy clay and sand loam.
Cover Crop (type, management)	Mixture Couch and Brome grasses. Mowed frequently.
Storage	Runoff retention basin.
Application System	Solid set sprinkler irrigation.
Operational Problems	Slight odours from stored effluent.

Plant K

Products	Similar to Plants I and J.
Years of Operation	Nine.
Wastewater Flows	160 m ³ /day.
Land Area	20 hectares.
Wastewater Pretreatment	None.
Soil Characteristics (type, land area)	Heavy clay.
Cover Crop (type, management)	Native grasses.
Storage	Winter storage lagoon (December to April).
Application System	Sprinkler irrigation using portable rain guns.
Operational Problems	No significant problems.

Plant L

Products	Cheese, butter, milk powder, concentrated milk.
Years of Operation	20
Wastewater Flows	3190 to 4550 m ³ /day (year round).
Land Area	34 hectares.
Wastewater Pretreatment	Sedimentation.
Soil Characteristics (type, land area)	Coarse sand with 10 cm of sandy loam topsoil.
Cover Crop (type, management)	Mixture of Reed canary and Couch grass, swamp grasses and forest.
Storage	Runoff retention basin.
Application System	Solid set buried sprinkler irrigation with high pressure rain guns.
Operational Problems	No significant problems.

Plant M

Products	Mozarella cheese.
Wastewater Flows	7 m ³ /day (year round).
Land Area	0.8 hectares.
Wastewater Pretreatment	None.
Soil Characteristics (type, land area)	Clay loam. Low slope.
Cover Crop (type, management)	Native grasses.
Storage	None.
Application System	Solid set above ground sprinkler irrigation in summer. Broad application in winter.
Operational Problems	No significant problems.

Plant N

Products	Processed turkeys.
Wastewater Flows	454 m ³ /day (seasonal).
Land Area	3.2 hectares.
Wastewater Pretreatment	Settling basin.
Soil Characteristics (type, land area)	Sand located on a gravel bed.
Cover Crop (type, management)	Native weeds and grasses.
Storage	None required.
Application System	Modified ridge and furrow using deep trenches.
Operational Problems	Clogging of the trench walls with suspended solids.

Plant 0

Products	Dehydrated animal by-products.
Years of Operation	Five.
Wastewater Flows	$0.3 \times 10^6 \text{ m}^3/\text{yr.}$
Land Area	70 hectares.
Wastewater Pretreatment	Primary and secondary treatment.
Soil Characteristics (type, land area)	Information not available.
Cover Crop (type, management)	Reed canary. Harvested for forage.
Storage	Winter lagoon storage (six months).
Application System	Solid set above ground sprinkler irrigation.
Operational Problems	None since modifications including secondary treatment and abandonment of self-propelled rain guns.

APPENDIX V

DESIGN EXAMPLE

APPENDIX V

DESIGN EXAMPLE

In order to illustrate the design procedure which has been previously discussed, a hypothetical food-processing plant has been selected as an example problem. The methodology discussed in the design manual is then used to design a land application system for the facility.

Statement of the Problem

A firm which specializes in the canning and marketing of vegetables has built a large processing plant in a small southern Ontario town whose population is 5,000 people. The plant handles and processes peas, corn, and green beans during June to August and carrots during September to November. Plant capacity is designed to handle the following production rates for each of the four vegetables.

Peas	- 90 metric tonnes/day,
Corn	- 100 metric tonnes/day,
Green Beans	- 140 metric tonnes/day,
Carrots	- 120 metric tonnes/day.

Following a meeting with the town council it has become evident that the sewage lagoon used to treat sewage wastes from the town are grossly inadequate to handle wastewater from the processing plant. As a result the food processor will be required to supply his own wastewater treatment and discharge system.

Following a preliminary investigation of available resources, the food processor has established that there is an extensive area of agricultural land approximately five kilometres from the proposed plant site. A preliminary economic and technical assessment of wastewater treatment alternatives has indicated that land application will be the most feasible method of wastewater treatment. The plant engineer has been given the task of designing the facility.

Solution to the Problem

a) Statement of Objectives

The management objective, according to the statement of the problem, is to provide acceptable treatment and removal of the wastewater from a pea, corn, green beans and carrot canning plant. The first three treatment objectives listed on page 1.2 of the design manual are therefore of primary importance in design of the system.

b) Assessment of Raw Wastewater Characteristics (refer to Section 3)

Based on operational experience in the plant, the design engineer has determined the following information regarding wastewater characteristics:

- 1) Since the processing season is relatively short, wastewater is generated during five months - from mid-June to mid-November.
- 2) Although wastewater flows have daily and weekly fluctuations the average flow rates are:

June 15 to August 31 - 2800 m³/day

September 1 to November 15 - 1500 m³/day

- 3) Concentrations of important wastewater constituents reflect the type of vegetables being processed. The following wastewater characteristics have been determined:

	June to August	September to November
BOD ₅ (mg/L)	500	2,200
Suspended solids (mg/L)	200	600
Total solids (mg/L)	3,000	2,000
Total nitrogen (mg/L as N)	50	30
Total phosphorous (mg/L as P)	15	10
pH	7.0	6.5

Temperature of the wastewater is below 25°C at all times.

In addition, since caustic peeling processes are not used in the plant, the sodium adsorption ratio is well below 6.0.

The sanitary sewage waste from the plant will be collected separately and conveyed to the town's collection and treatment system.

c) Assessment of Climate (refer to Section 4)

Since there is no wastewater generated during the winter months, the design does not need to take account of snowfall and freezing conditions. As a result climatic factors are not expected to limit the choice of alternative for land treatment and the use of climatic data will be left until later in the design.

d) Assessment of Soil-Plant System Characteristics (refer to Section 2)

Soil survey maps of the land area being considered as a potential application site indicate that there are two soil associations. The first is a deep somewhat excessively to moderately well-drained soil having a medium texture to moderately coarse-textured subsoil over gravel and sand. The second is a deep, somewhat poorly drained and moderately well-drained soil having a medium-textured or moderately coarse textured subsoil over fine and very fine sand.

The groundwater table, according to hydrologic reports, is approximately eight metres.

The area is relatively flat with an average slope of approximately one percent. The elevation ranges from 100 to 110 metres.

Since cations including light metals and heavy metals will not be of significant concentration in the wastewater, the cation exchange capacity of the soil is of minor importance in the design.

The primary treatment objective is renovation and removal of wastewater. Therefore, following a final choice of category and method of application, a suitable cover crop will be selected. This will be discussed in a subsequent section.

e) Choice of Category and Method (refer to Section 6.3)

A survey of the major criteria for application alternative (Sections 6.3.1 to 6.3.5) indicates that irrigation application is the most feasible alternative.

Application alternatives include spray irrigation, flooding, and ridge and furrow application. The spray irrigation method is chosen for the following reasons:

- 1) there is a sufficient area of available land to expand the facility if required; spray irrigation allows for a great deal of flexibility in the size of the system;
- 2) no land forming will be required;
- 3) the method allows maximum flexibility in the choice of a cover crop.

f) Pre-treatment Requirements (refer to Section 6.4.1)

Wastewater generated in the processing plant will be directly applied to the land. A survey of wastewater characteristics indicates that there will not likely be any problems associated with its application. Since the wastewater will not be stored prior to application, biological pretreatment or aeration for odour control will also not be required.

g) Loading Rate Determination (see Section 6.4.3)

Hydraulic loading rate

During the past canning season the company has conducted soil tests at the site and has determined soil permeability, infiltration rates and available water capacity. In addition, a small pilot study has been conducted on a 0.5 hectare plot of land to determine applications rates and to establish an acceptable irrigation schedule.

Equation (1), Section 6 can be used to calculate the seasonal water removal rate, R_w . Soil tests and experiments have established the following values:

Soil permeability = 1.0 cm/hr

Soil moisture storage capacity = 198 mm/yr

The procedure for determining soil moisture storage capacity for a specific crop and various soil textural horizons was illustrated in

Section 4.3. According to the soil moisture deficit map (referenced in Section 4.3), the water deficit (D) is 100 mm/yr for the above soil moisture storage capacity (for London, Ontario).

According to the soil description for the site (discussed earlier), the soils fall under the fourth classification in Table 2 and soil permeability (P_s) can be estimated to be approximately 1.5 cm/hr. For an assumed wetting period (T) of 8 hours and an irrigation cycle (C_i) of 8 days (moderately permeable soil), the annual soil permeability (P) can be calculated from Equation (2), Section 6.

$$P = \frac{P_s \cdot T \cdot d}{C_i}$$

in which

$$P_s = 1.5 \text{ cm/hr}$$

$$T = 8 \text{ hr/cycle}$$

$$d = 150 \text{ days/yr}$$

$$C_i = 8 \text{ days/cycle}$$

Therefore,

$$P = 225 \text{ cm/yr}$$

From Equation (1), Section 6,

$$R_w = P + D/10$$

in which

$$P = 225 \text{ cm/yr}$$

$$D = 100 \text{ mm/yr}$$

Therefore,

$$R_w = 235 \text{ cm/yr}$$

Required land area (R) is calculated from Equation (3), Section 6:

$$A_w = \frac{0.01 Q}{R_w}$$

From wastewater flow data,

$$Q = 332,500 \text{ m}^3/\text{yr}$$

Therefore,

$$A_w = 14 \text{ ha}$$

Therefore, approximately 14 hectares of land will be required to dispose of the wastewater.

Organic loading rate

Since organic matter concentration in the wastewater is relatively low ($BOD_5 = 500 - 2,200 \text{ mg/L}$) the organic loading rate will not be limiting.

Nutrient loading rate

The required land area for nitrogen removal (A_n) is calculated from Equation (4), Section 6:

$$A_n = N \cdot Q \cdot 10^{-3} / R_n$$

in which

$$N = (50 + 30) / 2 = 4 \text{ mg/L}$$
$$Q = 332,500 \text{ m}^3/\text{yr}$$
$$R_n = 250 \text{ kg/ha/yr} \quad (\text{Similar to Fescue, Figure 3})$$

Therefore, $A_n = 53 \text{ ha}$

Required land area for nitrogen removal is 53 hectares. Similarly, from Equation (5), Section 6 the required land areas for phosphorous removal (A_p) is calculated to be 19 hectares.

Inorganic loading rate

As discussed under wastewater characteristics, concentrations of inorganics are not expected to cause any problem. They do not need to be considered further.

h) Selection of Limiting Loading Rate (refer to Section 6.4.4)

The land area required for nitrogen removal ($A_n = 53 \text{ ha}$) is the limiting land area. The results from the pilot study have confirmed that this area is a realistic requirement.

i) Determination of Hydraulic Application Rate and Irrigation Schedule (refer to Section 6.4.5)

From the pilot study it was determined that an application period of six hours followed by an eight-day rest period were adequate to remove the wastewater. The amount of wastewater which could safely be applied during each irrigation cycle was 6.5 cm.

The land area used during each application cycle is calculated from Equation (7), Section 6:

$$A_i = A/C_i$$

in which $A = 53$ ha

$$C_i = 9 \text{ days}$$

Therefore, $A_i = 6$ hectares/day.

The maximum hydraulic application rate (I) will occur during June to August and can be calculated from Equation (6), Section 6:

$$I = .01 W/TA$$

in which $W = 2,800 \text{ m}^3/\text{day}$

$$T = 6 \text{ hr}$$

$$A_i = 6 \text{ ha/day}$$

Therefore, $I = 0.78 \text{ cm/hr.}$

Since the values of T , C_i , and I are all acceptable, according to the criteria discussed in Section 6.4.5, the design is adequate.

j) Buffer Zone Requirements (refer to Section 6.4.6)

Since the irrigation facility is located a considerable distance from any dwellings (the closest house is 500 metres from the border to the land), the Provincial regulatory agency will not require a buffer zone around the site.

k) Land Forming Requirements (refer to Section 6.4.7)

The topography of the site, as discussed earlier, is such that no land forming will be required for spray irrigation.

l) Underdrainage Effluent Collection (refer to Section 6.4.8)

Since the groundwater table is 8 metres, and neither the organic, nutrient or inorganic loading rates are limiting, no underdrainage system will be required.

m) Storage Requirements (refer to Section 6.4.9)

Of the four conditions which might require storage (Section 6.4.9), excessive rainfall, requiring temporary storage is the only one

which is applicable. The following conditions, however, should be considered:

- 1) because of topography there is little danger of runoff;
- 2) the land is not situated near a creek;
- 3) a cover crop which is relatively tolerant to water logging is being used;
- 4) the wastewater application rate (0.78 mg/hr) is much lower than the maximum allowable determined from field measurement (1.0 cm/hr).

Storage requirements, therefore, need not be considered for this system.

n) Distribution System Design (refer to Section 6.4.10)

For detailed design of the distribution system, the reader is referred to irrigation handbooks. This discussion will summarize the system components required for transmission and distribution.

The following is a list of major components for the system:

- 1) a wet well located at the processing plant;
- 2) transmission pumps with stand-bys to pump the effluent from the wet well to the site;
- 3) pipe line from the wet well to the site;
- 4) surge tank at the land application site;
- 5) irrigation pump with stand-by;
- 6) transmission mains;
- 7) lateral lines;
- 8) risers and spray nozzles.

In order to minimize initial capital investment, an above-ground solid set distribution system utilizing aluminum mains and laterals will be built.

The design of each of these components can be determined from standard irrigation system design practice and will therefore not be discussed here.

o) Monitoring Requirements (refer to Section 6.4.11)

Since groundwater table does not appear to be a problem and the land is not adjacent to a watercourse, the provincial Ministry of Environment has told the food processor that monitoring wells will not be required at the site.

In addition, wastewater characteristics will not affect soil salinity, pH and sodium adsorption ratio. Frequent soil monitoring will therefore not be required, although the plant engineer should periodically assess soil salinity, sodium adsorption ratio, nutrient content and soil structure.

p) Economic Analysis

For this section the reader is referred to Section 7. Since the discussion in this chapter is self explanatory, details will not be discussed here.

q) Specification of Constraints

Details are discussed in Section 8.

APPENDIX VI

FOOD PROCESSING PLANTS IN CANADA UTILIZING LAND APPLICATION SYSTEMS

APPENDIX VI

FOOD PROCESSING PLANTS IN CANADA
UTILIZING LAND APPLICATION SYSTEMS

Land application of wastewater has been adopted in a number of food processing plants in Canada. Those listed below represent a portion of these. They represent the results of an industry survey conducted by Stanley Associates Engineering Ltd. and also include plants which were identified in an "Inventory of Spray Irrigation Systems in the Great Lakes Basin of Canada"* . Although the list is not complete, it represents a cross-section of the food processing industry in Canada.

The following food processing companies are using land application systems for wastewater treatment:

Baxter Canning
Beardmore Division of Canada Packers
Borden Company
Big Isle Enterprises
Canada Dairies
Canadian Cannery
Cold Springs Farms
Empress Foods
Hardee Farms International
King Cole Ducks
Kraft Foods
Libby, McNeil and Libby
Malcolm Condensing
Maple Lodge Farms
New Dundee Creamery
Pine River
Produce Processors
Uniondale Cheese
York Farms Division of Canada Packers

* prepared by Reid, Crowther and Partners Ltd. for the Water Pollution Control Directorate, Environmental Protection Service, Report No. EPS 3-WP-73-5, October, 1973.

APPENDIX VII

LIST OF MANUFACTURERS OF IRRIGATION EQUIPMENT

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The following is a list of Canadian manufacturers of irrigation equipment:

<u>Manufacturer</u>	<u>Address</u>
Alcan Canada Products Ltd.	Royal Trust Tower, Toronto
American Portable Irrigation Co.	4th Avenue & Stafford Dr. Lethbridge, Alberta
BCA Industrial Controls	344 Lynn Avenue North Vancouver, B.C.
Berkeley Pump Co. (Canada) Ltd.	410 Finley Avenue Ajax, Ontario
Delhi Foundry & Farm Machinery Ltd.	P.O. Box 880 Delhi, Ontario
Fraser Supplies Ltd.	R.R. 1 Berwick, Nova Scotia
Grandview Industries Ltd.	65 Enterprise Road Rexdale, Ontario
ITT Fluid Handling Division, ITT Industries of Canada Ltd.	55 Royal Road Guelph, Ontario
Imperial Irrigation Co. Ltd.	106 Hillsvie Drive Richmond Hill, Ontario
Ireco of Canada Division of Ireco Industries Inc.	711 - 4th Avenue N. Lethbridge, Alberta
Jacuzzi (Canada) Ltd.	330 Humberline Drive Rexdale, Ontario
Monarch Industries Ltd.	889 Erin Street Winnipeg, Manitoba
Oliver Industries Ltd.	165 Okanagan Avenue Penticton, B.C.
Rain Bird Sprinkler Mfg. Co.(Canada) Ltd.	5337 - 180 Street Surrey, B.C.

<u>Manufacturer</u>	<u>Address</u>
United Machine Distributors Division of Hai Co. Mfg. Ltd.	2410 - 2nd Avenue S.E. Calgary, Alberta
Vanden Bussche Irrigation & Equipment Ltd.	P.O. Box 304 Delhi, Ontario
Van Seters R.J. & Co. Ltd.	P.O. Box 355 Unionville, Ontario

